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Thaddeus C. Johnson and Francis H. Sayles

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The report documents a study tour of the USSR to determine the current practices in analyzing the thermal regime of embankment dams on permafrost and in application of these practices in designing dams. The results of visits to earth and rockfill dams on permafrost in Siberia are summarized. Discussions with the designers of the dams, and with a construction manager and an operations manager, are recorded. The leading Soviet engineers and scientists specializing in analysis of thermal regime of embankment dams on permafrost were consulted,

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20. Abstract (cont'd)

and the discussions are summarized. Experimental facilities of institutes concerned with this question also were inspected.

Preface

This report was prepared by Thaddeus C. Johnson, Chief, Civil Engineering Research Branch, and Francis H. Sayles, Research Civil Engineer, Geotechnical Research Branch, Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory. Funding for this research was provided by U.S. Army Corps of Engineers Civil Works Work Unit, Agreement on Exchange of Scientists between the National Academy of Sciences of the USA and the Academy of Sciences of the USSR.

The tour described in this report was carried out in accordance with the terms of a Protocol signed on 17 June 1976 between CRREL and the Permafrost Institute of the USSR Academy of Sciences (App. A). The Protocol, in turn, was developed within the framework of Paragraph 12 of the exchange agreement between the National Academy of Sciences of the USA and the Academy of Sciences of the USSR. The Protocol also provided for two Soviet engineers or scientists from the Permafrost Institute to conduct a similar study in the USA on a topic related to cold regions science or engineering. This return visit has not taken place as yet.

EMBANKMENT DAMS ON PERMAFROST IN THE USSR

Thaddeus C. Johnson and Francis H. Sayles

INTRODUCTION

We conducted a study tour of the USSR during the period July 15 to September 15, 1976 to determine the state of the art of designing embankment dams on permafrost. The purpose of the study was to determine the state of knowledge in the USSR with regard to the thermal regime within and beneath embankment dams in permafrost regions, as well as related design techniques for controlling seepage. To accomplish the objective of the study, we obtained information from Russian technical literature, discussions with persons in the USSR having specialized knowledge of the study topic, and examination of embankment dams in operation or under construction in the USSR. In this report we present a summary of our activities during our two-month stay in the Soviet Union. The material is presented in chronological order, essentially without comment or analysis. A later report will present an assessment of the state of the art, including our analysis of the information summarized herein.

The study tour began with our arrival in Moscow on July 15. We were met by Dr. V.T. Balobayev, head of the geothermal laboratory of the Permafrost Institute in Yakutsk, who (with Dr. V.P. Mel'nikov) was our host and companion for our stay in the USSR. Also meeting us was Yu. A. Satbayeva, who was our interpreter for all the meetings and visits that took place in Moscow and Leningrad. Balobayev arranged lodging for us at the Academy of Sciences hotel on Leninskiy Prospect in Moscow and outlined for us the program tentatively scheduled for our study tour. We were to start on July 16 with meetings at the office of the Scientific Council for Geocryology, followed by a trip to the Republic of Yakutia in Siberia for a month to visit the Permafrost Institute and sites of existing embankment dams and other structures on permafrost. Following the on-site tour, the program included a return trip to Moscow and finally a visit to Leningrad for discussions with engineers and scientists on the principles and criteria used to analyze, design, and operate embankment dams on permafrost.

An itinerary and a list of persons contacted in the USSR are presented in Appendix B. The principal scientific and engineering institutions visited during this study tour included:

1. Scientific Council for Geocryology, Academy of Sciences of the USSR, Moscow.
2. Permafrost Institute, Academy of Sciences of the USSR, Yakutsk.
3. Research Institute of Bases and Underground Structures (NIIOSP), Moscow.
4. Moscow Construction-Engineering Institute, Moscow.
5. Moscow State University, Moscow.

6. Hydroproject Institute, Moscow.

7. Hydroproject Institute, Leningrad Division.

8. Hydrotechnical Scientific Research Institute (VNIIG), Leningrad.

MOSCOW, JULY 16-19, 1976

On July 16 we met with Dr. N.A. Grave, Deputy Director of the Permafrost Institute, and Dr. Balobayev. We discussed the proposed program of our study tour in the USSR and some of the problems that our Soviet colleagues were having in scheduling meetings with organizations and individuals outside the Academy of Sciences. Apparently, July and August are popular vacation periods in the Soviet Union and also periods of intensive field work by researchers, so many of the individuals with whom we wished to confer would not be available until the latter portion of our tour. We were advised that we would probably not be able to visit the site of Khantaika Dam located near Noril'sk (see Fig. 1), although an effort

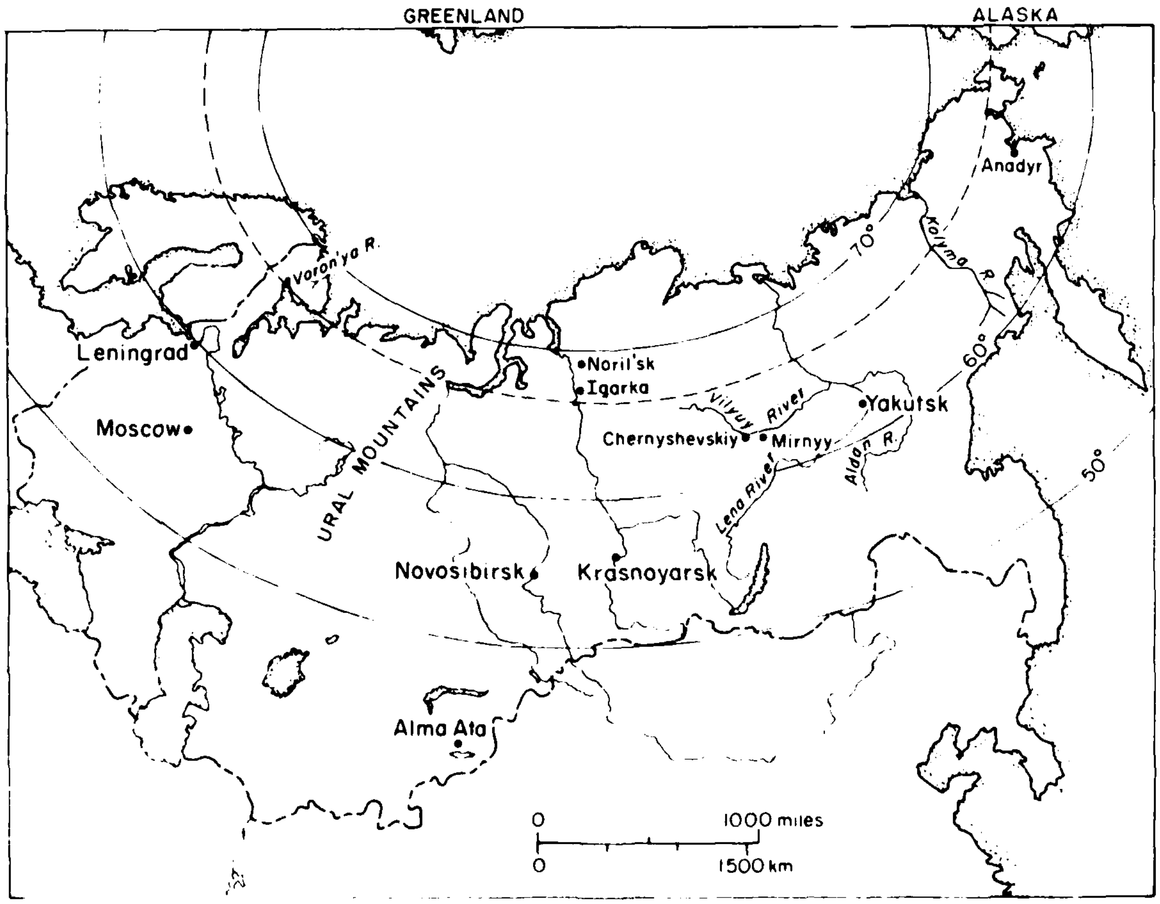

Figure 1. Sites of interest to the study.

would be made to arrange this trip. We were particularly interested in visiting Khantaika Dam since the permafrost at the site is warmer and therefore less stable than that at Vilyuy Dam, which we would see in Yakutia. Also, existing smaller embankment dams in the Noril'sk region would be of interest since much of the early construction of dams on permafrost was done here. It was unfortunate that we were never able to visit the Noril'sk region.

On Monday, July 19, Dr. S. Ye. Grechishchev, a scientist at the Research Institute of Hydrogeology and Engineering Geology (VSEGINGEO), met with us in the offices of the Scientific Council for Geocryology to discuss his studies on thermal cracking of dams on permafrost. He described his observations of transverse vertical cracking across the crest of a small (6-m-high) irrigation dam in Yakutia constructed of a soil classified in the Soviet system as supis (clayey silty sand). The cracks appeared in the crest surface within 1.5 m of the vertical walls of the outlet structure. These walls were constructed of horizontal timbers supported by wooden piles which were braced at the top. Dr. Grechishchev attributes these cracks to the thermal contraction of the frozen embankment and has written a paper describing this phenomenon ("Theoretical and Experimental Studies of Temperature Stresses and Strains in Earth Dams During Winter," CRREL Draft Translation 449). To protect against this type of cracking, a layer of gravel 2 m in thickness is being used at the crest of embankment dams on permafrost in the USSR. He suggested that wooden rods embedded in soil as reinforcement could be used to prevent cracks of this type. Dr. Grechishchev pointed out that difficulties in understanding and using soils information in the foreign literature arise because of the lack of detail of the soil description. A translation and comparison of the various soil classification systems would be a step toward exchanging precise information involving research on soils. Dr. Grechishchev gave us the following ranges of plasticity index applicable to the soil classification system used in the USSR:

Plasticity index	Classification
0 - 7	pisok (sand)
7 - 12	supis (clayey silty sand)
12 - 17	suglinok (sandy clayey silt)
> 17	glina (clay)

YAKUTIA, JULY 21 - AUGUST 15

In the Republic of Yakutia, our base of operations was the Permafrost Institute, located on the outskirts of the city of Yakutsk. We devoted several days to familiarizing ourselves with the Institute, its research facilities, library, and the special research interests of each of its departments or laboratories. From here also we visited two water supply dams for the city of Mirnyy, tailings dams for the diamond mines at Mirnyy, the Vilyuy hydroelectric dam and reservoir at the town of

Chernyshevskiy, the site of a proposed new dam (Vilyuy No. 3) on the Vilyuy River, a series of small irrigation dams on the Suola River southeast of the city of Yakutsk, and a field research station at Syrdakh Lake located about 80 km east of Yakutsk.

Yakutsk, July 21

On July 21 at the Permafrost Institute, Dr. P.A. Danilovtsev, Deputy Director, described the history, mission and organization of the Institute as well as the scientific investigations that were in progress. The Permafrost Institute has been at its present site since 1941, having been established at that time as the Permafrost Station. From 1941 to 1960 its purpose was to investigate the problems of building on permafrost and developing water supplies. In 1960 the Institute was reorganized under the Siberian Division of the Academy of Sciences (at Novosibirsk) to make scientific investigations leading to practical decisions, to provide education in the cold regions sciences, and to develop a scientific base in a permafrost area.

The work at the Institute falls into four categories:

1. General geocryology - study of the distribution and types of permafrost.
2. Thermophysics - heat flow investigations.
3. Physical properties of frozen soils - deformation and strength studies, conducted in permafrost in the laboratory's underground rooms behind the institute's main building.
4. Engineering geocryology - investigations of various practical problems requested by clients.

The Permafrost Institute has three field stations under its control. One is located in the town of Chernyshevskiy and is concerned with collecting data and performing studies on the Vilyuy Dam and Reservoir; a second one, at Igarka (near Noril'sk), is concerned with laboratory studies of the physical and mechanical properties of permafrost; and the third is a high-altitude station at Alma Ata, which studies permafrost above elevation 3500 m and is concerned with the composition, structure, and distribution of permafrost.

The Permafrost Institute in Yakutsk consists of 11 laboratories, computer facilities (both digital and hydraulic analog), a heat balance center, a geophysics center, field test areas and underground test rooms in permafrost. Two projects that currently occupy 50 to 60% of the total effort of the Permafrost Institute are consultation during construction of the Baikal-Amur railroad, where both high and low temperature permafrost as well as discontinuous permafrost are encountered, and studies related to the gas pipeline to the Far East which will extend about 2800 km through a region of permafrost.

Also on July 21, Dr. Balobayev, Head of the Geothermal Laboratory of the Permafrost Institute, explained that research in his laboratory includes studies of the thermal regime in frozen ground, processes of thawing and freezing, heat exchange at the air/ground interface, thermal properties of earth materials, and changes in natural processes caused by man's activities. The geothermal laboratory is organized into four study groups:

> One group studies the thermal regime of frozen ground throughout the USSR, using deep boreholes (average depth about 500 m) drilled by others using either air or diesel fuel as drilling fluid, and with diameters from 2 to 30 cm. When compressed air is used in drilling, cooling by expansion occurs which reduces the thermal disturbance of permafrost. Balobayev feels that it takes about 2 years for the thermal regime to stabilize after drilling. Temperatures are measured using thermistors (and a Wheatstone bridge) in boreholes filled with either diesel fuel or with air. Many of the boreholes in northern Siberia are drilled with light-weight, man-portable, equipment. Soil samples are taken to determine the thermal properties of the earth materials, which together with temperature data are used to construct isotherms.
>
> A second study group is concerned with the heat balance at the air/ground interface, including such factors as the ground surface cover, slope orientation, etc.
>
> A third group, headed by Dr. Zabolotnik, studies the seasonal freezing and thawing of ground. One of their tasks is to predict the changes in seasonal thawing due to changes in the surface cover caused by activities of man, such as the building of roads, or natural disturbances such as fire. This group is studying the Baikal-Amur railroad where it crosses permafrost that exists because of the insulating effect of a thick surface layer of lichens.
>
> The fourth group (led by Gavrilyev) studies the thermal and physical properties of frozen soil in the laboratory. Balobayev commented that the thermal conductivities published by Kersten in the USA are higher than those determined in the Soviet Union.

Dr. Balobayev noted that he personally is occupied mainly with analytical calculations. He said he developed an equation to calculate the ground temperature from surface temperature measurements, and that ground temperatures at the site of Vilyuy Dam predicted by this method agree with temperatures measured at the site and published by R.M. Kamenskiy.

Mirnyy, Chernyshevskiy, and Vicinity, July 22 - 29

On July 22 we flew via Yak 40 jet to Mirnyy and then drove about

100 km northwest to the town of Chernyshevskiy, the site of the Vilyuy Hydroelectric Station, and the nearby Permafrost Research Station that had been mentioned on the previous day by Danilovtsev in Yakutsk. On our arrival we were treated to an interesting walking tour of the town conducted by V.A. Medvedev, manager of the hydroelectric station.

The town of Chernyshevskiy was established to support the construction of the Vilyuy Hydroelectric Station and has a population of about 8000 housed mainly in prefabricated wood frame dwellings. These frame dwellings are now being replaced by the same type of precast concrete apartment house that is common throughout the USSR. Pile foundations were used where bedrock is deep, while footings were used where the depth to rock was less than 3.5 m.

The buildings are heated by hot water that is distributed from a central heating plant having 13 electric boilers of 2.5 MW each. When asked why the houses were not heated directly with electricity instead of electrically heated hot water, Medvedev replied that the transmission of hot water is more economical since it also serves the second purpose of warming the drinking water and sewage pipes that are laid in the same utilidors. The utilidors and outside piping are insulated with waste cloth, which has to be replaced every 5 to 6 years. We also saw a large greenhouse, which was said to have made it unnecessary to bring in fresh vegetables, and also a nursery school and a day-care center. We were shown an attractive indoor swimming pool and gratefully accepted Medvedev's invitation to try it.

On July 23, Dr. Snegiryev, Director of the Permafrost Research Station in Chernyshevskiy, and his researchers B.A. Olovin, V. Makarov, and I. Konstantinov described the work at the station. Of particular interest is the investigation in progress on the Vilyuy Dam and Resevoir.

The site for the dam and reservoir is characterized by Palaeozoic and Mesozoic sedimentary and volcanic rocks. Intrusive rocks are from the lower Triassic period. At the dam site, the rock to a depth of 30 m contains small fissures, some of which were open, containing only ice.

The average annual air temperature at the site is -8.2°C and the permafrost temperatures vary from -2° to -6°C, depending upon the orientation of the ground slope with respect to exposure to the sun. Permafrost thickness varies from 200 to 300 m, but a through-talik (unfrozen zone extending entirely through the permafrost) is found beneath the river bed at the dam site. The extent of the talik was determined by projection of temperature measurements in shallow borings. A thermal analysis of the river valley using an electrical "model EJ-12" differential analyzer was conducted by Professor Kudryavtsev of Moscow State University, who also concluded that the talik beneath the river bed extended through the permafrost. We were told that a thermal analysis of the embankment was not made prior to construction, having been considered unnecessary because the dam was planned as an unfrozen

rockfill dam founded on thaw-stable bedrock. Also no prediction was made of the change in the permafrost table within the limits of the reservoir that would result from establishment of a permanent pool.

We were told that researchers at the Hydrotechnical Scientific Research Institute (VNIIG) in Leningrad made thermal model studies of the dam and attempted to account for air convection within the rockfill. While the model studies showed that the effects of air convection could be neglected, data now being obtained from the completed dam show that this conclusion was incorrect.

An interesting field study of the thermal regime of the dam's downstream rockfill zone was being conducted by the Permafrost Research Station at the time of our visit. Olovin said that the study was initiated when ice was observed in the upper reaches of the rockfill. The investigation included temperature measurements taken at a number of locations within the rockfill section and foundation, as well as measurement of the circulation velocity and relative humidity of the air within the voids of the rockfill at a depth of 0.5 m below the surface. Also heat flow meters were installed in the rockfill below the outer surface of the embankment. To measure the air circulation in the rockfill, an air collector approximately 1.5 m wide was laid on the surface of the downstream rockfill slope from a point near the toe up to about one-third the slope height. The cross section of the concrete air collector was in the shape of a channel whose concave side faced downward against the rockfill. Small cup-type anemometers and hygrometers were positioned at critical points in the collector and in the pores of the rockfill.

Preliminary results from these measurements indicate that cold dense air descends through the downstream portions of the rockfill during the winter and contacts the relatively warm and moist foundation soils, where the descending air is warmed and picks up moisture. This warm moist air then moves upward through the interior portion of the rockfill until it contacts the cold rocks located near the surface of the downstream slope, where the moisture condenses and freezes on the rocks. As a result of this air convection and the accompanying moisture and heat removal from the base of the rockfill, the talik beneath the former river bed is being frozen, a result that had not been anticipated by the designers of the dam.

In addition to the moisture from convection, moisture also enters rockfill pores from precipitation and occasional tailwater backup. The ice formed from the tailwater is solid and remains at the base of the fill, while that from precipitation is distributed in the rockfill depending upon its temperature distribution. As the voids in the rockfill become filled with ice, the air currents are damped and the amplitude of the temperature cycle decreases with time.

As part of the investigation of ice in the rockfill, a trench was excavated through a rockfill cofferdam. Photographs of the cross section

of the cofferdam were used to estimate the amount of ice that occupied its pores from the different sources of water, i.e. rain, tailwater backup, or moisture migration by air circulation.

Following Olovin's explanation of investigations concerning Vilyuy Dam, V. Makarov, inventor of the liquid single-phase type thermal pile, stated that two small dams about 14 m high had been frozen using thermal piles. At one dam an ammonia-gas two-phase thermal pile (essentially a Long Thermal Pile) was used, and at the other dam single-phase liquid-type thermal piles were installed. The liquid-type thermal piles, which are charged with jet aircraft fuel, operate on the principle of convection of liquids. In winter, the cold dense liquid falls to the bottom of the pile where it is expanded to a lower density by heat given off by the ground surrounding the pile. The warmed liquid rises and is replaced by colder liquid, establishing a continuous convective circulation. This convection process continues throughout the winter and effectively lowers the ground temperature; in summer the convection ceases.

During the weekend of July 24-25, we were treated to an extensive tour of the reservoir by motor vessel. We observed the shores of the reservoir formed by the Vilyuy Dam and also visited two field stations for collecting data on the reservoir. The reservoir is over 470 km long and has a maximum width of 15 km. The maximum depth near the dam is about 70 m and its volume is about 36 km^3. Ice covers the reservoir for as long as 220 days each year but the ice thickness does not exceed 1.2 m. The reservoir follows a tortuous path up the Vilyuy and Chona Rivers. Waves reach heights of 2 m or more in long stretches of the reservoir. A wave observation and meteorological station situated over 200 km upstream of the dam is used to provide data for the operation of the dam.

At a field station about 49 km upstream from the dam, temperatures in the reservoir and on the shore as well as meteorological data such as air temperature, wind velocity and direction, amount of precipitation, etc., were being recorded. Konstantinov told us that shore erosion has been observed in relatively few locations because a large percentage of the shore consists of thaw-stable bedrock. In less stable permafrost the shore is receding at a rate of about 1.8 m per year. At locations where permafrost soils were being eroded, the bank was undercut just above the water level, apparently by wave action as the soil thawed. When the depth of the undercut reaches about 1.2 m, the bank caves into the water and another cycle begins. Temperature readings from borings indicate that the permafrost has thawed to depths of about 9 to 10 m along the wall of the reservoir below the waterline over a period of about 8 years.

On July 27 we visited the city of Mirnyy, its two water supply dams, a tailings dam and an open-pit diamond mine. The city of Mirnyy is founded on permafrost extending to a depth of about 300 m. Within the 3-m active layer the soils are mainly sandy loams, with veins of ice

and total ice content of about 30 to 40%. The removal of snow within the city seems to have had a cooling effect on the permafrost, which shows temperatures of -1° to -2°C outside the city and -3° to -4°C within the settled area.

Concrete piling is used extensively for the foundations of the newer precast concrete buildings. Piles are 8 to 10 m in length and are usually placed in thawed holes. Some of the more recent buildings are supported on thermal piles of the type described by Makarov (see above), which use kerosene as a heat transfer liquid. The thermal pile cooling units are encased in the center of the concrete piles. The portions of the piles above the ground surface are exposed to the ventilated area beneath the buildings. Apparently this heat transfer from the permafrost through the concrete pile to the thermal cooling pipes and thence back through the exposed concrete to the air beneath the building is sufficient for preserving the permafrost. The older wooden buildings are supported by crib-type wall footings resting on the ground surface. An air space is maintained beneath the floor, but ventilation appears to be obstructed by the banking of sawdust around each building.

The open pit diamond mine at Mirnyy is circular in shape with haul roads spiraling downward around the side-walls. The mine's diameter at the surface was about 1 km, and the bottom of the pit was about 200 m below the ground surface at the time of our visit. Frozen soil (Kimberlite ore) was being excavated by drilling, blasting, and mucking. It is estimated that the diamond-bearing ore (in a columnar deposit termed a "pipe") extends to a depth of about 1200 m.

We inspected two water supply dams located on the Irelyakh River near Mirnyy. Both dams are founded on permafrost. The older one, a temporary dam built in 1957, is a 9-m-high earthfill dam, with a timber crib filled with loam serving as an impervious core. This core extends to the fissured sedimentary bedrock. The spillway consists of a timber flume with wooden crib wing-walls and removable wooden flashboards across the flume. Temperature observations over a 7-year period of operation showed that the foundation thawed to a depth of approximately 50 m due to the flow of water through the spillway.

The second dam, completed in 1964, is a 20.7-m-high earthfill dam located about 2 km upstream from the temporary dam. This main Irelyakh River Dam is founded on about 8 m of Quarternary deposits consisting of frozen sandy gravel and silty clays having up to 60% ice content. Beneath this deposit lies fractured dolomitized limestone and marl with ice content up to 10%. The embankment cross section consists of a large silty clay central section with zones of sand beneath layers of gravel on both the upstream and downstream slopes. A silty-clay-filled cutoff trench extends through the Quarternary deposits to bedrock along the centerline of the dam. Because thawing of the high-ice-content foundation soils would engender unacceptable settlements, a line of vertical cooling pipes was installed at 1.5-m spacing along the axis of the

embankment. The cooling pipes extend down through the embankment and about 3 m into the foundation. (Subsequently in Moscow, G.F. Biyanov, the engineer who had been in charge of construction of the dam, told us that the permafrost thawed an additional 6 m during construction, and consequently the cooling pipes were extended by an additional 6 m). Each cooling assembly consists of two concentric pipes. The outer one is connected to a manifold through which cold air is blown down the annulus between the inner and outer pipes, returning up through the inner pipe to be discharged to the atmosphere. Air is blown through the system only when the ambient air temperature is lower than -15°C.

During the first winter of operation of the cooling system, the dam foundation and core became almost entirely frozen along a line of merged ice-soil cylinders around each freezing pipe. Only two unfrozen sections were detected and these became frozen in the second winter. To reduce the velocity of seepage from the reservoir in the talik beneath the embankment during initial operation of the cooling system, an additional row of cooling pipes was installed along the downstream toe of the dam across the old river bed. After the central ice-soil cylinders had merged, chilling at the downstream toe was no longer required; however, the pipes still remain in place.

Horizontal cooling pipes were installed beneath the concrete spillway, which is located through the left abutment. To protect the adjacent embankment against thawing as a result of heat from the water discharged over this spillway, a line of vertical cooling pipes was installed along the embankment side of the spillway discharge chute, which is paved with concrete slabs on a gravel filter.

Temperature measurements in the spillway area show that the permafrost is thawing beneath the spillway chute toward the embankment. Also, during discharge, water has flowed under the slabs and melted the permafrost beneath the chute. As a result, not only is the thawing front advancing toward the dam but also the concrete slabs have become misaligned and moved from their original positions, thus inducing further degradation of the permafrost. To arrest this thawing, it is planned to install additional freeze pipes and to raise the spillway in order to increase the pool capacity and thereby reduce the amount of water discharged during periods of high runoff.

The Irelyakh River Dam has had a permanent pool behind it for over 12 years, and although the degradation of the permafrost in the spillway area had not been arrested completely at the time of our visit, the Soviet specialists stated that their experience in operating this dam indicates that the frozen type of dam has definite advantages in permafrost areas.

We also visited two dams used for disposal of mine tailings and wastes from the Mirnyy diamond processing plants. Our hostess for this visit, G.M. Sheynfeldt, hydrotechnical specialist from the Yakutniy

Diamond Mining Trust, said that the hydraulic fill method is used to construct tailings dams to heights of 40 m. The permafrost beneath the tailings dams and sedimentation ponds thaws and consolidates as the dams are formed. Evidently the foundation soils at the sites we visited are thaw-stable as no adverse consequences of permafrost degradation were apparent.

On July 28, V.A. Medvedev of the Vilyuy Hydroelectric Station described the operations of the plant and took us on a tour of the existing powerhouse, the dam and the new powerhouse that was under construction. The last of the four 77-MW Kaplan turbines of the existing powerhouse (on the right bank) was put into operation in 1968, which brought the total output up to 308 MW. The operating head of 68 m was reported to be the highest in world practice for turbines of the Kaplan type. The second powerhouse (under construction on the left bank) with its four Francis turbines will bring the total capacity of the station to about 648 MW. The four 85-MW Francis units will be used for base load while the Kaplan units will be used for peaking. The 40-m-wide spillway has a design capacity of 6000 $m^3 s^{-1}$ and the discharge is controlled by a single tainter gate. Before the dam was built, the thickness of the ice in the river was reported to be as great as 2.5 m. Now the average ice thickness is about 0.7 m with a maximum of 1.2 m. Ice forms in November and has not been a problem at the intake because it melts in place by the end of June before reservoir draw-down takes place.

Based on experience with the operation of the existing powerhouse, some of the features were changed in the design of the new one. For example, no butterfly or Dow valves were included for the turbines of the new plant, and the gates in the new plant are to be operated by cables rather than hydraulic pistons. Also, the forebay structure and the intake cranes are to be enclosed in the new plant to reduce the ice problems associated with the gate and stop-log operations. In both the new and the existing powerhouses the electrical switch yards are housed in buildings that are electrically heated so that the temperatures will not fall below -30°C.

As we took a walking tour of the dam we noticed a sag in the crest starting about one-third of the way from the left bank. Mr. Medvedev said the higher part near the left bank coincides with the location where flood discharge was permitted during construction. Since closure and construction to the crest level took place much later here, less time for settlement has elapsed than at other stations on the dam. In general, settlements in the rockfills have averaged about 2-3% of the height, the rockfill having been merely dumped into place without sluicing or compacting. Subsidences at various elevations within the embankment are being measured by means of anchors buried along a vertical line. A wire attached to each anchor is brought to the crest of the dam through a cased hole. Changes in elevation of the upper end of the wire are referenced to a fixed benchmark.

Medvedev also took us into the grouting gallery beneath the dam. He explained that since it was expected that ice within the fissures of the bedrock would be melted by heat from the reservoir, a grouting gallery about 3.5 by 3.5 m was provided at the base of the impervious zone of the embankment. In addition to contact grouting along the axis of the dam and to curtain grouting in the talik beneath the river bed to a depth of 30 m, both of which were performed during construction of the dam, the permafrost zone was to be grouted in stages from the gallery as the ice in the fissures in the bedrock melted during maintenance of the reservoir. After eight years of operation, grouting with a sanded portland cement grout was accomplished to depths of 70 m, which indicated that the average rate of thawing was about 8 m per year.

Medvedev said that the embankment construction, including rockfills, filters and core material, had been continued even through the winters. Soils for the impervious zone, with a total volume of about 10^6 m^3, were excavated from a borrow area on the right bank of the river and placed in a stockpile during the summer for later placement in the dam. The impervious borrow was a gravelly silty clay residual soil derived from weathering of dolerite, occurring in a layer 0.6-1.5 m in depth. The soil had an extremely wide range of grain sizes, from gravel sizes to soil fines. After removing the topsoil, the gravelly silty clay was excavated from the borrow pit in layers by allowing the sun to melt successive layers of soil prior to excavation.

It was necessary to place soils in the impervious zones at low ambient air temperatures because the summer season was fully devoted to excavating material from the borrow pits and stockpiling it so that natural drying could take place. The essential features of the winter placement of core material were as follows. Any frozen soil from the stockpile was set aside and unfrozen soil was placed in heated beds of dump trucks that hauled the soil to the impervious zone. After dumping, the soil was spread in 0.7-m layers with dozers; compaction was by 25-ton (cargo capacity) trucks using 2 to 10 passes. To prevent the surface of the existing layer from freezing before the next layer was placed, a salt solution was spread on the surface. In extremely cold weather (-40°C) the surface was heated with a mobile jet engine mounted so that the flame was directed downward on to the soil surface beneath an inverted pan. This flame was passed over the surface just prior to placement of the succeeding soil layer. Although the heating method was considered inefficient, it was used on a trial basis to assure a bond between successive layers of soil. (Biyanov told us later in Moscow that use of the jet engines proved ineffective and was discontinued). The in-place density was specified as 2 Mg/m^3.

On July 29, we journeyed downstream along the Vilyuy River by automobile and then by a powerful river vessel to the proposed site for the hydroelectric station called Ust'Botuobiya. The proposed station is also called Vilyuy No. 3, to distinguish it from the first station on the Vilyuy River in operation since 1968 and the second stage powerhouse

now under construction. Our host for this trip also was V.A. Medvedev. The site is located on the Vilyuy River near the entrance of a tributary, the Botuobiya River. At this point in the Vilyuy River, the channel is bordered by terraces of moderate width. Borings were in progress at the site, and we were able to examine the cores and discuss them with the field geologist, L.P. Belyakov.

The site is geologically very complex. The bedrock is marl, relatively massive but weathered to clay in some places, with ice in the fissures. Clay minerals in the marl are mostly chlorite and hydromica. The upper 20 to 30 m of the rock has ice contents as high as 20%. Above the rock, about 8-15 m of unconsolidated Quaternary deposits are found, with an ice content generally of 40 to 50% and exceptionally to 70%. A talik exists under the river channel, but with a maximum depth not exceeding 90 m, it does not extend completely through the permafrost. Ice-wedge polygons 15 m in diameter are found at the right valley slope. The permafrost temperature at the valley bottom is about -8°C, while beneath the left valley slope it is about -3° to -4°C.

The cores were being obtained mainly with a hardened steel bit and single-tube core barrel about 150 mm in diameter and 4 m in length, without the use of any drilling fluid. Sometimes water was used to cool the core barrel and remove the cuttings. Core recovery was nearly 100%, and sometimes the core was found in an expanded condition. To measure ground temperature both thermistors and ordinary thermometers were used. DC electrical resistivity surveys also were conducted to determine the boundaries of ice-rich ground.

We saw a preliminary plan of the structures for a hydroelectric station with capacity of 350 MW, including a dam 66 m in height, and a spillway with capacity of 7300 m^3/s. The spillway and powerhouse were shown in a central location, approximately at the present river channel.

Yakutsk and Vicinity, July 30 - August 16

On July 30, we returned to the city of Yakutsk and the Permafrost Institute. The following weekend was occupied by a boat trip up the Lena River from Yakutsk to a farming village. Since the Lena River is a main artery for commerce, there was much barge traffic on the river and also construction-related industries along the banks including cement plants, aggregate processing plants, timbering operations, etc.

Near Yakutsk the Lena River is perhaps 1 to 1.5 km wide; islands and sand bars are common. A comprehensive system of sighting targets has been installed on the river banks to assist in navigation.

Most of the first week of August was spent at the Permafrost Institute laboratories and outdoor testing facilities. On August 2, Dr. V.P. Mel'nikov, Chief of the Geophysics Laboratory, described the activities of his laboratory, which are directed toward three principal objectives:

1. Development of the theoretical aspects of physical/chemical processes in frozen strata, as a basis for application of geophysical methods.

2. Experimental in-situ investigation of the properties of frozen ground. Problem-solving tasks at construction sites are conducted by the methods of electrical resistivity and by induced or natural (self-induced) polarization.

3. Observations of the variations in ground properties during the annual cycle.

Mel'nikov explained that the main thrust of his work is toward the use of induced polarization as a means to determine the location, extent, and types of in-situ earth materials in the frozen or unfrozen state. Currently direct-current electrical resistance methods are used to locate ice masses such as wedges or lenses in permafrost, and then subsurface borings are required to determine their depths and thicknesses. The induced polarization technique consists of applying a DC voltage to the earth materials for a short time (say 3 minutes) and then observing the decay with time and distance. If alternating current is applied, the observed phase shift is used to delineate the subsurface materials. The polarization method can be used to determine the change in electrical properties of frozen soil with time. The Soviets are using this technique to study changes in soil due to the annual weather cycle and the related soil structure, pore size distribution, heterogeneity, etc. Some of the field experimental work in the polarization studies is conducted at specific construction sites as well as at field sites controlled by the Permafrost Institute.

The head of the General Geocryology Laboratory, Nekrasov, explained that his group is concerned with the geographic aspects of permafrost and produces maps which show the distribution of permafrost in the USSR and the rest of the world. Information for the Soviet maps is obtained from subsurface exploration for minerals, geological explorations, and observations made by teams from the Permafrost Institute. One set of maps of northern Siberia shows permafrost depths of about 1500 m and thickness of ice cover up to 6 or 7 m. Off-shore permafrost borehole data are scarce in the Soviet Union but the information available off-shore in the Arctic Ocean indicates discontinuous permafrost depths of up to 100 m and island permafrost 5 to 10 m in depth. There are two other groups in the Soviet Union that map permafrost: one is at Moscow State University and the other also in Moscow at GOSSTROI (State Committee for Construction), which uses the maps for planning purposes.

On August 3, in Kamenskiy's absence, studies of bases and foundations were described by two researchers, Gaidayenko and Deryugin. These studies are mainly concerned with the design and installation of piling in permafrost. In general, building foundations in Yakutsk are of concrete piling with ventilation beneath the buildings to maintain the

permafrost frozen. Piles are installed either in drilled holes or after pre-thawing. It is more economical to place reinforced concrete piles in fine-grained soils by melting holes in the permafrost with steam points, since after the hole is thawed all that remains to be done is to insert the pile and allow the natural slurry to freeze back. However, special equipment is required for this method, and recently, percussion drilling and augering of holes have come into use. The percussion drilling is used in frozen gravel or rock and is accomplished with a 40 to 50-cm-diam. drill. Water is added during drilling, and cuttings are removed by a mucking bucket. The production rate is two piles per 8-hr shift. For about three years, augers have been used in fine-grained soils to drill 65-cm-diam. holes; slurry backfill is placed around the pile and allowed to freeze before loading the pile. For this method, the production rate is five to six piles per 8-hr shift. For some foundations undersize holes are drilled and the piles are driven into the holes.

Cast-in-place concrete piling in permafrost is still in the experimental stage. Field tests at the Permafrost Institute have demonstrated that it is possible and economical to use cast-in-place concrete piling if the concrete is maintained above 0°C until it gains sufficient strength to resist damage due to freezing. The following procedure is used for installing these piles: 1) drill the hole at the diameter desired, 2) place a reinforcing steel cage in the hole and a 2.5-cm pipe in the center, 3) vibrate the concrete into the hole, and 4) pass electrical current between the reinforcing cage near the perimeter of the pile through the concrete to the pipe at the center axis of the piles. The electrical current provides sufficient heat to allow the ordinary portland cement concrete to cure. The pipe along the central axis also provides access for measuring the temperature of the curing concrete. In permafrost with a temperature of -3 to -4°C, experience gained at the Permafrost Institute shows that thawing occurs to a radius of 30 to 40 cm beyond the 15-cm radius of the pile. A period of five to six months is required to freeze back to the original temperature of -3 to -4°C. The cost of cast-in-place piles is about half that of precast piles, and the former also have higher bearing capacity because they have a rough surface, giving greater skin friction. However, they are not yet widely used, because the quality of the piling is difficult to control and the technology is complicated.

The time required for piling freezeback depends upon the season of the year. In May, freezeback for drilled piles requires 15 to 16 days; for steamed piles three to four months and for cast-in-place piles five to six months.

No thermal piles have been used in Yakutsk, where the temperature at a depth of 10 m is -3° to -4°C. At Mirnyy conditions are more severe with temperatures of -2 to -5°C in high-ice-content ground, requiring general use of thermal piles. In Yakutsk, thermal cooling devices have been used to date only where they have had to be added to piles around

which thawing had occurred. Also no forced ventilation is used in Yakutsk, even for the power plant.

At the Permafrost Institute, pile load testing in permafrost is performed by applying 50% of the calculated pile capacity for three days, and then an additional 20% of the calculated load is applied every three days until failure occurs. Failure is assumed when the subsidence rate of the pile reaches 5 mm/day.

We visited some of the cold testing rooms of the Permafrost Institute that are maintained without artificial refrigeration in a permafrost tunnel complex located just to the rear of the Institute's main building. The coldrooms are about 15 m below the ground surface in a frozen deposit of thinly stratified fine sand. The constant room temperature provides an ideal laboratory for long-term tests where constant temperatures are important. At the time of our visit, long-term ball penetration tests and model pile tests were in progress. Also unconfined compression tests were being performed using an electrically driven universal testing machine located in a small shaft off the main tunnel.

Dynamic load testing of frozen soils is conducted in the permafrost tunnel and in artifically refrigerated coldrooms in the main building of the Institute. Vibratory, seismic, and impact type loadings are being used to determine dynamic moduli, deformation and strength of frozen soils.

On August 4, we conferred with Dr. P.I. Mel'nikov, Director of the Permafrost Institute and father of V.P. Mel'nikov. Dr. Mel'nikov promised to endeavor to get the authorities at the Academy of Sciences in Moscow to arrange a trip for us to Noril'sk and Khantaika Dam. He also agreed to prepare a proposed U.S. itinerary for V.P. Mel'nikov and V.T. Balobayev, who were to accompany us on our return to the United States.

Also on August 4, Mr. Li showed us the hydraulic analog computer at the Institute, which is capable of solving one and two-dimensional thermal problems taking into account the latent heat of fusion. This computer utilizes a series of vertical tubes, reservoirs, valves, and a pump to simulate heat flow problems. In addition to the analog device, the Institute has a small digital computer (16-K word memory) which was shown to us by Korotich.

Dr. Are, Chief of the Laboratory for Thermal Physics of Frozen Soil, explained that one of the main aims of his research is to investigate the interaction of water bodies with permafrost. To this end his laboratory is studying thermokarst lakes, arctic seashores, and the shores of large reservoirs. In small reservoirs the degradation of the shores results simply from melting, but in larger water bodies wave action, thermal stratification of the reservoir, currents, etc., play an important part of the process. Syrdakh Lake, an active thermokarst lake located about 100 km northeast of Yakutsk, has been instrumented and is

being studied in detail. (Further information on this study was provided later during our visit to Syrdakh Lake.) One of the unknown factors in the degradation of permafrost beneath a body of water is the effect of the boundary layer at the bottom of the lake. Thermistors were placed along the bottom of Syrdakh Lake to determine the temperature and velocity of the water, but because the response time of the instruments was too long, this part of the investigation was terminated in favor of instrumentation for determining average heat balance between solar and geothermal heat flow (presumably heat flow meters was used). Information obtained from the shore line studies is to be used in the preparation of norms (SNIP) for GOSSTROI (State Committee for Construction). Some of the results from the arctic shore studies are described in the Proceedings of the Third International Conference on Permafrost.

During the weekend of August 7, R. Tzhan of the Permafrost Institute treated us to a tour of the Khorobutskaya irrigation system and described his investigations of its embankment dams. The system consists of a series of four small dams on the Suola River, located about 80 km east of Yakutsk. The dams were built during 1959-66 by collective farmers to flood the hay fields (alasses) upstream of the dams. The dams have stored water about one month each year since 1966, from about the end of April to the end of May. Each of these long, low dams has a gated wooden flume to control the pool elevation and to drain the reservoir. One of the dams (no. 3) was selected by the Permafrost Institute as typical of these irrigation dams. In 1969 Tzhan started monitoring changes in soil moisture, temperature distribution in the soil, and depth of thawing of the permafrost. Monthly temperature measurements in a deep hole indicated that the depth of the active layer is about 3 m and the permafrost temperature at a depth of 10 m is about -2°C. Temperature observations in shallow holes beneath the reservoir indicated that flooding had practically no effect on the thawing of the permafrost. We saw a line of six boreholes along a transverse section of the dam, in which Tzhan said temperature measurements showed that the dam is completely frozen in winter and completely thawed in summer. The downstream portions of the timber spillways are protected from the sun with wooden shades to reduce thawing in this area during the summer. Tzhan oncluded from his study of dam no. 3 that the time required for the stabilization of the temperature regime was about 7 to 8 years; short periods of flooding did not influence the average permafrost thermal regime, and these small dams are considered to be seasonally frozen dams on permafrost.

One of these small dams (no. 4) was breached during the spring of 1976 due to thawing around and beneath the wooden outlet structure. This structure was founded on ice-rich silt. Tzhan said he never observed any subsidence of the structure, and no temperature measurements were made; probably some thawing occurred beneath the central structure each year during the spring storage period, but the structure was supported by the adjoining embankments that rested on frozen ground.

Apparently, by a process much like the phenomenon of thermokarst, a small pond was formed behind the outlet structure during the summer, thus promoting further thawing beneath the structure during this period. It was reported that the dam showed no distress until the spring of 1976 when it failed quickly, presumably by settling and water piping around the structure.

On August 10, we visited a field station at Syrdakh Lake where about 20 scientists, technicians and support personnel were studying the processes of heat exchange of the atmosphere-hydrosphere-lithosphere by using the lake and the surrounding larch taiga as a case study. The amount of instrumentation and the number of personnel involved in the study were impressive. Some of the data acquisition methods have been automated but most of the data are recorded manually around the clock. Tishin, a researcher at the field station, conducted a tour of the site and explained the research activities. Measurements taken included wind velocities, water temperature at many depths, atmospheric humidity at different heights above the lake, water velocities near the water surface and at several depths, albedo, air temperatures, precipitation, evaporation and heat flow (determined by means of meters at the bottom of the lake). Every year the temperature and heat balance sensors are changed and calibrated. To measure the albedo of the surrounding forest, a 26-m high wooden tower was erected. The temperatures of the wood of individual trees are periodically measured. Once each month soil moisture contents are taken to depths of 3 m. Columns of soil 1 m in depth are weighed periodically as part of the vegetation-moisture-heat balance studies.

As part of the shore erosion studies, two steep bank areas 20 m high containing ice wedges were sluiced in 1973 with a hydraulic monitor to initiate the erosion process, and were sluiced again in 1975. The rate of shore retreat and the subsequent healing processes are being observed. The area that was washed in 1973 had nearly healed itself in 1976.

The shore on one side of the lake is active because the prevailing wind drives the waves against it, causing thermal as well as mechanical erosion. Measurements show that this shore eroded 3 m in four years. Temperature measurements below the bottom of the lake indicate a through-talik in which the ground temperature was about +1.5°C at the 100-m depth.

On August 11, we visited the gas-fired thermoelectric plant at the city of Yakutsk, and were received by the Director, N.V. Kal'chenko. This plant is elevated on reinforced concrete piling embedded in permafrost. Air for process cooling within the plant is drawn from an intake located in the air space beneath the structure, thus serving the purpose of ventilating the air space. Reportedly, the permafrost table is rising beneath the power plant and no settlement is occurring. We left the plant after only a few minutes because our host appeared not only

inhospitable, but openly hostile.

At the Permafrost Institute on August 11, N.P. Anisimova from the Laboratory of Underground Waters described her laboratory and field studies on groundwater in permafrost areas. The laboratory studies are concerned with the chemical composition of the water and changes that take place during freezing and thawing. The field studies are concerned with the location of underground water supplies and with icings. Icings are of interest because each one represents a source of underground water and because they cause great problems for man-made structures. Two methods recommended by Anisimova's group for controlling icings are to keep the water underground by building a frozen subterranean dam, or to collect the groundwater and conduct it away from the icing.

The principal methods of locating groundwater supplies are to study the geology and locate taliks. Geophysical methods are used, but drilling boreholes is still the most reliable method of locating and confirming the existence of groundwater supplies.

During this period we spent a long weekend on an extended river cruise on the Lena and Aldan Rivers. While in Yakutsk, we also spent portions of several days in the library of the Permafrost Institute in search of papers related to the design, construction and operation of embankment dams on permafrost. At our request, the Permafrost Institute made for us a copy of a number of papers. A list of publications that were obtained here and later in Moscow is given in Appendix C. These have been translated from Russian to English and are available as CRREL Draft Translations.

MOSCOW, AUGUST 17 - SEPTEMBER 3

Since our arrival, we had stressed to our hosts a wish to confer with engineers and researchers who develop and use methods for analyzing the thermal regime of dams on permafrost. After spending a month in Yakutia, we were convinced that the key specialists and organizations were to be found in Moscow and Leningrad. Consequently it was with considerable expectation and optimism that we arrived in Moscow on August 17.

August 18 and 19 were relatively unproductive, and were devoted to developing a schedule and the necessary appointments for our conferences in Moscow and Leningrad. Balobayev and V. Mel'nikov made all the arrangements in consultation with us. Our headquarters during the stay in Moscow was the Scientific Council for Geocryology, where P. Mel'nikov maintains an office at no. 11 Fersmana Street. We also conferred with the Scientific Counselor at the US Embassy, Dr. E. Loebner, and with his assistant Dr. Gosnell.

On August 20, we met briefly at the office of the Scientific Council for Geocryology with S.S. Vyalov, of the Scientific Research Institute

for Foundations and Underground Structures (NIIOSP). He was departing that very day for the construction site of the Baikal-Amur Railway (BAM), where he was involved in work in progress. He said his scientific work had not been concerned directly with the design of embankment dams on permafrost but with the properties of frozen soil and ice with regard to underground structures and foundations. He mentioned the Moscow Construction-Engineering Institute (MISI), Hydroproject Institute (Gidroproyekt), the Leningrad branch of the latter (Lengidroproyekt), and the Hydrotechnical Scientific Research Institute (VNIIG), as sources of information for dams on permafrost. Professor Vyalov said that to date high embankment dams on permafrost have been constructed in the USSR only on rock with low ice content. He felt, however, that an embankment dam as high as 50 m could be constructed on permafrost other than sound rock if the ice content in the foundation is less than 20%. He noted that the rock at the Kolyma Dam site is not good.

Visit to NIIOSP (Scientific Research Institute for Foundations and Underground Structures), August 23

We were graciously received by G.V. Porkhayev, Science Director, and spent most of the day here, including a lavish luncheon served in our conference room. Conferring with us also were D.I. Fyodorovich, Yu. O Targulyan, N.K. Pekarskaya and B.A. Rzhanitsyn. We learned that NIIOSP is not concerned with hydrotechnical structures, but only with foundations for buildings. We were informed that the special organizations dealing with thermal regime of dams are (in Moscow) Gidroproyekt and the Moscow Construction Engineering Institute (MISI); (in Leningrad) Lengidroproyekt and the Hydrotechnical Scientific Research Institute (VNIIG), and (in Gork'iy) the Gork'iy Construction Engineering Institute (Professor Bogoslovskiy). Nevertheless, our hosts offered a brief commentary. Professor Porkhaev said there are several 3 to 7-m high dams near Vorkuta with two-stage foundation cooling systems. To date, high dams on permafrost are constructed only on rock without ice inclusions, as for example, at Vilyuy and Kolyma. We asked about Khantaika Dam and were told it has some special problems but we should ask Lengidroproyekt about it.

We were given a tour of the institute, visiting the following laboratories:

1. Laboratory of Mechanics of Frozen Soils (Vyalov's Lab.). Here we saw also two coldrooms and a freezing cabinet for freezing remolded samples.
2. Laboratory of Building Foundations on Weak Soils. Here we saw a specialized centrifuge machine (one of 20 in the USSR) in which they run tests not only on soils alone but also tests on model footings bearing on soil samples of up to 200 kg.
3. Laboratory of Soil Testing. At this laboratory and at PNIIIC (Industrial Scientific Research Institute of Engineering Construction Investigations), the principal standard soil testing methods used throughout the USSR are developed.

4. Laboratory of Chemical Grouting. Examples of their work are the development of chemical (e.g. $NaSiO_3$) and cement grouting methods for Aswan Dam, and the grouting of loess soil supporting a heavy building to arrest the consolidation of the loess triggered by an increase in its moisture content.

5. Laboratory for Large-Scale Testing. Here large-scale footings and pile foundations are tested. We saw a pre-cast footing, 4 m long x 1.2 m wide being tested under a load of 3 kg/cm^2.

Visit to MGU (Moscow State University), August 24

We were received by V. A. Kudryavtsev, Dean of the Faculty of Geology and holder of the Permafrost "Chair" (kafedra) at Moscow State University, and conferred with him and with Dostovalov and V.G. Melamed. Professor Kudryavtsev gave us copies of his book "Fundamentals of Frost Forecasting in Geological Engineering Investigations" (now available as CRREL Draft Translation 606). His group at MGU conducts experimental and theoretical research on permafrost, with a budget of 0.5 million rubles and 130 scientific workers. The projects on which their research is applied include hydrotechnical construction, oil pipelines, railways, highways, and nuclear power stations. They maintain an active collaboration with Gidroproyekt and have advised them on such large dams as Bratsk and Ust'-Illimsk on such topics as general problems of frozen ground, methods of earth filling at Bratsk, and the predicted distribution and depth of seasonal freezing. We asked whether they have made any studies of the thermal regime at Khantaika Dam, and were told that former MGU student Felofeev (now with Lengidroproyekt) made predictions of the thermal regime beneath and within the dam. He used one-dimensional analyses and also made 2- and 3-dimensional analyses with the hydraulic integrator. Their former student Krivonogova (also now at Lengidroproyekt) uses physical models to study thermal regime of dams.

In the knowledge that the methods he mentioned were worked out some years ago, we asked whether the one-dimensional analyses make use of the simplified equations published by Tsytovich, Ukhova and Ukhov (available as CRREL Draft Translation 435). Professor Kudryavtsev said "no," that he and his colleagues use the equations given in his own book plus some others such as these of Leybenzon. He said they account for convection by using two parabolic equations instead of one Stefan-type equation. We asked whether he has any field measurements to confirm his predictions; he said there are 10 years of data from Bratsk and 3 years from Ust'-Illimsk (both of those dams are located in non-permafrost zones), but not on or under the dams themselves, for which he has no data.

When asked what approaches will improve the prediction methods, Professor Kudryavtsev suggested the following: 1) more accurate ac-

counting of radiant thermal balance, 2) methods of 2- and 3-dimensional modeling, 3) algorithms for electronic computers, and 4) more accurate accounting of factors such as covers and geologic conditions.

We were given a tour of the museum at MGU by its director Sovelyev, who formerly occupied the position now held by Professor Kudryavtsev. In the afternoon we toured some of their laboratories, observing studies of water in frozen soil by the calorimetric method and by nuclear magnetic resonance, electro-osmosis in thawed soils, unfrozen moisture determination by sublimation, and thermal conductivity studies using the guarded hot plate. We also saw a freezing cabinet equipped for a temperature of -80°C.

Summing up the day at MGU, we had interesting tours and discussions, and were treated very cordially, but learned little about advances in thermal analysis of dams. Perhaps they were making advances they did not care to discuss, but it seemed more likely that they were not at the forefront of the problem of development and application of methods of thermal analysis of dams on permafrost.

Visit to Gidroproyekt (Zhuk Designing, Surveying and Scientific Research "Hydroproject" Institute) August 25

At Gidroproyekt we were received by G.K. Sukhanov (General Director), I.C. Moisseyev, V. Ya Sherskov, and A.L. Kuznetsov (the latter an engineer from Lengidroproyekt, the Leningrad branch of Gidroproyekt). After we stated that our primary interest was in the thermal regime of embankment dams on permafrost, we were told that Gidroproyekt in Moscow does not investigate this question, nor even design embankment dams on permafrost. Our interest then turned to learning how the investigations and design of dams is organized in the USSR and what organizations contribute to this task.

We learned that three of the divisions of Gidroproyekt are involved in the design of dams on permafrost: the Moscow, Leningrad and Kraznoyarsk offices. The Moscow office does not design embankment dams on permafrost, although Sukhanov has designed concrete dams on permafrost. The Gidroproyekt organization as a whole carries out a complete range of design functions, including site and materials investigations; preparation of designs with different variants such as concrete, earthfill or rockfill; comparison of technical and economic factors; choice of one of the variants; and detailed design.

Gidroproyekt uses other organizations when needed, such as MGU, GISI (Gor'kiy Construction Engineering Institute) and VNIIG (Hydrotechnical Scientific Research Institute). If a project is designed by another division, such as the Leningrad office (Lengidroproyekt), the design is sent to the main office in Moscow for review and possible changes. It goes then to the Ministry of Energy (Minenergo) where it is reviewed again; Minenergo also invites other organizations, including

constructors, to review the design. Then, if it is a large project, it is submitted to GOSSTROI (State Committee for Construction) for approval.

In reality, then, there are separate organizations for financing projects, constructing them, operating them, etc. For example an organization called Glavvostokgidroenergostroi (Main Administration for Eastern Hydroelectrical Construction) constructs all hydroelectric projects in Siberia. During construction, Gidroproyekt has a design group at the site to supervise construction and make design changes. The assistant chief engineer of the project is head of the group, which at Vilyuy Dam, for example, numbered 30 to 40 persons. The same group may install instrumentation or it may get another organization to do so; at Vilyuy Dam, for example, VNIIG installed the instrumentation. VNIIG, which also is under Minenergo, performs these and other services for Gidroproyekt, but has many other clients as well.

We were informed that Gidroproyekt also has a Scientific Research Center in Moscow. G.F. Biyanov, formerly chief engineer in charge of construction of the Vilyuy project, is now employed at the Scientific Research Center (see below).

Following the meeting at Gidroproyekt we had no appointment until after the weekend, and we spent considerable time in book stores seeking several technical books on subjects in our area of interest, but without success. We also obtained a card to use the Lenin Library and started a lengthy process of figuring out how to use the library.

Visit to MISI (Moscow Construction Engineering Institute), August 30

We had hoped to meet with Professor Tsytovich, head of the Department of Soil Mechanics, but were informed he was hospitalized after suffering a heart attack. In his absence we met with Messrs. Shlyapin (acting head), Kronik, Malyshev, Merzlyakov, and Pogocyan. Professor Kronik proved to be very well informed and willing to discuss questions of interest with us, and most of the dialogue was with him. He said that the Tsytovich-Ukhova-Ukhov Monograph (CRREL Draft Translation 435) was the first step of the department in investigating the thermal regime of dams on permafrost. This work was finished in the 1950's, but was written only in 1965, and published only in 1971. He said the method is still useful for small earth dams, but is not satisfactory for rockfill dams because of air convection within the rockfill sections. N.A. Mukhetdinov, of the Krasnoyarsk branch of VNIIG, has published important papers on air convection in rockfill dams in the journal, Trudiy VNIIG (see CRREL Draft Translations 580, 586, and 616).

Professor Kronik said that, in recent years, Bogoslovskiy and his disciples at GISI have worked to improve and correct their earlier works on thermal regime. Zhdanov, a student of Bogoslovskiy, has a recent paper, published in the journal, Cbornik Trudov GISI, which we could find in the Lenin Library.

Kronik and his colleagues at MISI are now working toward a better accounting for the construction period, better definition of initial conditions, improved thermophysical parameters for thermal analysis, and a better understanding of the influence of ice content, creep, and cryogenic structure. They now have data from the first high embankment dams on permafrost in the USSR, and they are comparing the observed temperatures with the calculated ones. They are using both 1- and 2-dimensional analyses, and for some special problems even a 3-dimensional analysis, on which a graduate student is now working. Also they are using elastic theory in the finite element method for calculating the stress state in rockfill dams in the north. Responding to our questions, Kronik said that on small dams the comparison of observed and calculated temperatures is good, while on high rockfill dams it is unacceptable. We asked which are the high dams in question, and he replied Vilyuy Dam, three dams at the Khantaika project, and one in Magadan.

We asked which calculation method was used to compare with the observed temperatures, and Kronik said that his department used Melamed's calculations (given in Kudryavstev's book referred to above). We asked whether they had also predicted the temperature regime in the subsoil beneath a rockfill dam, to which he replied that since the work of Ukhova, they have done nothing further on this question. We asked whether Lengidroproyekt, which designs the large embankment dams on permafrost, consults with Kronik and his colleagues. He replied vaguely that now there is a special laboratory at MISI for problems relating to construction of dams on permafrost.

We asked Kronik whether, prior to construction of the Vilyuy Dam, he had made a forecast of the thermal regime that would develop within and beneath the dam. He said no, but that Shadrin of VNIIG made a calculation for Vilyuy based on a physical model, including a physical model of air convection from which they decided that the effect of convection could be neglected. (Air convection has since proved to be of overriding importance.) Kronik suggested we see Povrich and Smirnov of VNIIG about this. We asked whether he had made thermal calculations for the Khantaika Dam. Kronik said that many investigations were made, especially of the properties of the soils and materials including their thermal properties, and of methods of placement of soils in the dam. He said that he is now making calculations of the thermal regime, which would be published later.

We asked whether the three dams at Khantaika have hard rock foundations, and were told that the main dam does, but another, with a maximum height of 37 m, rests on 15 m of complex Tertiary deposits over rock. The upper part of the 15 m, which had an ice content of about 50%, was removed, while the rest with 10-15% ice content was left in place. Kronik said this was published by Ten in the journal, Hydrotechnical Construction.

We asked Professor Kronik to show us the comparison of measured and calculated temperatures at Khantaika Dam. He said that he has nothing to show us because he arrived from Khantaika only yesterday with the measured temperature data, and has not yet drawn them up. He plans to publish it later in Hydrotechnical Construction. We asked him to show us something on Vilyuy Dam; he said it is already published, and then sketched for us his recollection of the limits of frozen and thawed zones, which were very similar to what we had been shown by Olovin at the site. We asked whether Professor Kronik had made any calculations for Kolyma Dam, and he said he had, but that Mukhetdinov made a calculation including air convection in the rockfill zones. We asked whether Mukhetdinov's method has been tested against measured temperatures. Kronik said it has been tested against measured temperatures at Vilyuy Dam; it seems to be satisfactory for low dams but Kronik doubts it will be good enough for high dams.

We asked Kronik to compare the approach to thermal calculations used by his institute (MISI) with that of Bogoslovskiy's institute (GISI) and with that of the Permafrost Institute. Kronik said that the personnel of MISI have good relations with GISI and that sometimes they collaborate with Bogoslovskiy on calculations. Kronik said Bogoslovskiy's group specializes in thermal calculations, while his laboratory studies thermal regimes and other problems as well. He said Bogoslovskiy uses a theoretical approach, and with theory alone it is sometimes difficult to make practical recommendations for such a complex structure as a dam. He said that Bogoslovskiy's work was based only on heat conduction, and only recently he and his colleagues tried to include convection. Also now they are including concepts of the physics of the pertinent processes. Professor Kronik said in the USSR the thermal regime of small dams has usually been calculated by the Bogoslovskiy method. The thermal regime of Kolyma Dam, for example (a high dam), was calculated by Lengidroproyekt with the help of the VNIIG branch in Kraznoyarsk. He said that now some of Bogoslovskiy's colleagues (Zhdanov for example) are attempting to calculate high dams. They made a prediction of the temperature in the case of the high dam at Khantaika, but unfortunately the prediction does not coincide with the measurements.

Professor Kronik said that in addition to Bogoslovskiy and his colleagues, VNIIG also has done important work on thermal calculations. He suggested we confer with Sh. N. Plyat of VNIIG, who has written a monograph on thermal calculations in concrete dams. VNIIG now is trying to use the same method on earth dams. Kronik also suggested that we confer with Tsybin. He said that both the Permafrost Institute and the Tsytovich/Kronik group at MISI are strong in thermal physics, as is also the Kraznoyarsk Division of VNIIG, and another institute called VNIIVODGEO.

Kronik said the direction most researchers are taking now is toward better definition of the non-stationary temperature regime. Mukhetdinov's

calculations agree well with observations for the first six months, but diverge excessively later on because many physical cryogenic processes not yet well understood. Kronik said that Tsytovich and Ukhova first thought the downstream rockfill zone at Vilyuy Dam would be ice-filled, but calculated that the temperature would have to be -70°C for the rockfill zone with a porosity of 40% to become ice-filled. They concluded therefore that ice filling would not occur, which of course proved later to be incorrect.

We found the dialogue with Professor Kronik most interesting and helpful, especially in indicating which Soviet specialists have published important papers on thermal regime of dams, and which Soviet specialists we should attempt to visit during the remainder of our stay in the USSR. We wished to confer further with Professor Kronik, and arranged to meet with him again on September 2.

Dialogue with G.F. Biyanov, September 1

We had hoped to visit G.F. Biyanov, former Chief Engineer in charge of construction of Vilyuy Dam, at the Scientific Research Institute of Gidroproyekt. This visit could not be arranged for some reason that was not made clear to us, but V. Mel'nikov and Balobayev did succeed in arranging for Biyanov to call upon us, at the Scientific Council on Geocryology.

Biyanov mentioned to us some of the dam construction projects he had worked on prior to Vilyuy; these included some of the Volga dams, Bratsk Dam, and a dam in Korea. He then told us about Vilyuygestroi, the construction trust that built not only Vilyuy Dam but also the dams on the Irelyakh River at Mirnyy, the tailings dams at Mirnyy, and the 16-m and 20-m dams at Oyur-Yuregye and Sytykan, located about 400 km north of Chernyshevskiy. Biyanov said that the Irelyakh Dam at Mirnyy was built during two years including the summer, and consequently the small talik under the river was enlarged, increasing in depth by about 6 m. The designers had intended that cooling pipes be installed to only 3 m below the existing small talik, but it was necessary to extend them through the 6 m of additional thawing. We asked why the line of cooling holes near the downstream toe was installed, and Biyanov said that he put them in, even though they were not required by the design. When he finished the main line of holes at the end of January he had only two months of good freezing weather to freeze the curtain and feared that seepage in the bottom of the talik would prevent freezing of the curtain. So he quickly put in the downstream system and circulated air to freeze the soil and reduce the seepage velocity so that the main cutoff at the centerline of the dam could freeze solid.

We said that we understood no cooling pipes were planned across the spillway, and he said this was true, that the project was planned as a thawed spillway beside a frozen dam, with an upstream-downstream freezing

curtain to separate the two. Biyanov felt that this was an error. He had wanted to put in vertical cooling pipes across the spillway as well as an upstream-downstream curtain at the edge of the spillway, but the design engineer disagreed and it was decided to install only the upstream-downstream curtain plus a system of horizontal cooling pipes across the spillway. He said that the spillway was intended to function only in May and occasionally in summer after heavy rains. But Proalmaz, the trust that operates the big diamond mines at Mirnyy, decided to raise the storage pool by 2 m by building a small dike across the upstream approach to the spillway. The dike was pervious and seepage water flowing over the slabs in the spillway channel caused thawing and settlement, leading to the present poor condition of the slabs. He said the cooling tubes, which are operated in the winter when the temperature is below -15°C, effectively freeze a cut-off, but that it thaws again each summer. He noted that an air cooling system using suction to circulate air is better than a pressurized system, since heat is added to the air at the joint of discharge instead of at the point of entry. However, cooling pipes that extend 40 m or deeper into the ground require a pressure type cooling system to ensure positive circulation of the air.

We discussed Vilyuy Dam only briefly, because its construction is recorded in detail in the literature. Biyanov said that water was added during placement of embankment materials only at the lower portion of the downstream rockfill zone, in the summer of 1964, and as a salt solution during placement of the impervious zone. He referred to the jet engines mentioned in the literature as having been used to heat the embankment materials during winter placement operations, and said that the temperature of the exhaust was about 500°C, but the engines were ineffective and their use was discontinued.

We asked Biyanov what knowledge he had of plans for the dam called Vilyuy No. 3, or Ust'Botuobiya. He said that an early plan was to prethaw the rock, let it consolidate, and then build the dam on it. But the most recent geological and thermal data show that conditions are not as bad as had been feared, so perhaps the plan will be changed.

Meeting with P.A. Bogoslovskiy, September 2

Before leaving the U.S., we had informed P.I. Mel'nikov of our interest in conferring with P.A. Bogoslovskiy, but had been told that the latter is no longer at the forefront of work in the USSR on the thermal regime of dams on permafrost. Having heard on August 25 that Gidroproyekt still uses Bogoslovskiy as a consultant, we asked our hosts to arrange for us to go to Gor'kiy to visit GISI. V. Mel'nikov and Balobayev tried to arrange the visit but it seemed that the necessary authorizations could not be obtained in the short time still remaining to us. They did succeed in arranging for Bogoslovskiy to come to Moscow to visit us, however. We met with him at the Scientific Council on Geocryology.

Professor Bogoslovskiy is head of the Department of Hydrotechnical Structures, of GISI. GISI is a teaching institute (like MISI), under the Ministry of Higher Education, and its main function is the preparation of undergraduates and graduate students in engineering. GISI also carries out research, and Bogoslovskiy's research work is on the temperature regime of hydrotechnical structures such as dams, penstocks, channels, canals, etc. The Department of Hydrotechnical Structures has 10 teachers, 6 of whom have scientific degrees. There are about 100 students, some of whom also assist with the research. The department has a coldroom where researchers can build and operate physical models. They also have a hydro-integrator.

We asked Professor Bogoslovskiy to identify the dams for which he and his colleagues had made thermal regime calculations and subsequent temperature measurements. Bogoslovskiy replied that such calculations and measurements had been made for dams at Dolgoye Lake (1943) and Irelyakh (Mirnyy), both earth dams without seepage, and a dam with seepage located north of the city of Magadan. The latter was designed as a dam without seepage, but seepage began in the foundation after one or two years. Bogoslovskiy then developed a method for calculation of heat transfer with seepage (see Reference 15 cited in CRREL Draft Translation 435). Professor Bogoslovskiy gave us a copy of his paper on 3-dimensional calculation of the stationary temperature regime without seepage (CRREL Draft Translation 601). He also referred to a paper he wrote in 1971-72 on the two-dimensional analysis of Dolgoye Lake Dam. He said he also analyzed the Irelyakh Dam but doesn't remember where or when it was published. The comparison of the predicted and measured temperatures is given in Reference 15 of CRREL Draft Translation 435.

We asked whether he made any calculations for Lengidroproyekt of the thermal regime for Khantaika Dam, and asked him to describe them for us. He said that he made such calculations, but didn't elaborate further. We asked whether he has compared his calculated temperatures with those recently measured, and he replied it is too early to do so. He said that some materials in the dam had thermal properties differing from those he had used, and we must wait until a few more years of measured temperatures are obtained before making such a comparison. We asked whether he had calculated the thermal regime for Vilyuy Dam, and showed him the measured temperatures given on p.55 of Biyanov's book. He said that he did make some calculations, which gave results that were roughly similar to the measured temperatures.

We asked whether GISI has developed a method for accounting for the effect on the thermal regime of air convection within the rockfill zones. Bogoslovskiy said "yes," Mukhetdinov had done so; V.A. Zhdanov had also developed such a method by using a modified form for turbulent flow such that $v = ai + bi^2$ for the air flow instead of the usual assumption of the applicability of Darcy's law. We asked Professor Bogoslovskiy whether his preconstruction calculations of thermal regime at Vilyuy Dam had included the effect of air convection, and he replied

that they had, but not in such an exact way as the methods developed by Mukhetdinov and Zhdanov. We asked about the source of the moisture that has been found in the form of ice filling the downstream rockfill zone. Bogoslovskiy said that Zhdanov shows it comes from condensation of the moisture-laden air, formed first as needle ice which in time became a solid ice filling of the pores. We asked whether he has made a prediction of the thermal regime that will be developed in Kolyma Dam, and were told that he has not been asked to do so. We asked whether Lengidroproyekt has engineers on their staff who have made such calculations, and Professor Bogoslovskiy said that he believed so, but he could not recall their names. He said that Lengidroproyekt also asked other institutions such as VNIIG and the Permafrost Institute to make such calculations. Professor Bogoslovskiy said that all dams in the USSR with artifical refrigeration are under 20 m in height. In his opinion, embankment dams with heights greater than 50 m on permafrost whose frozen state must be preserved require refrigeration.

Second Meeting With Ya. A. Kronik at MISI, September 2

We asked Professor Kronik to elaborate further on the effect of air convection in rockfills. He said that Mukhetdinov made calculations of the effects of air convection without considering moisture transfer, while Zhdanov assumed that the moisture would be transformed to pore ice. We referred to Vilyuy Dam, and asked, with such low temperatures existing in the downstream rockfill zone and with the pores filled with ice, how convection can continue. Kronik said that only the lower portion of the downstream rockfill zone is filled with ice, and even part of that ice filling is seasonal. Kronik feels that as time passes the ice content still increases, until ultimately the pores in the rockfill zone will be completely filled. At present, probably the rockfill zone is not solidly frozen, but rather there are large masses of rockfill that are solidly frozen but are separated by unfrozen zones where air convection still occurs.

We asked Kronik to elaborate further on Khantaika Dam. He explained that Khantaika is somewhat smaller than Vilyuy Dam, and the atmospheric moisture at the Khantaika site is about 2.5 times greater than at Vilyuy. Consequently, it appears that air convection has already ceased at Khantaika Dam because the downstream rockfill zone has become ice-filled. The ice-filled zone does not extend completely through the alluvial gravel subsoil, and seepage is taking place in the talik and is expanding the talik on both sides.

Kronik said Khantaika Dam began to be operated only last year (1975), and gradual thawing of the core of the dam is now being observed. He is following the problem with some concern, because the thawing is causing settlement of the core. Already with only the top half of the core thawed, settlement of 3.5 m has been observed, or more than 10% (apparently Kronik was referring to the smaller of the embankments at the Khantaika project). He said that the rockfill has

settled about 1.5 times less in the frozen rockfill than in the thawed portion. Professor Kronik said he is studying this problem too, including the question of creep in the ice filling. He said that all this will be published next year in the third volume of "Engineering Geology of the USSR," a publication of MGU with Chief Editor G.A. Golodkovskaya, entitled "East Siberia." There will be a chapter "Hydrotechnical Construction," written by Kronik. Also his department at MISI will prepare a series of papers on these questions for publication in the Minenergo journal, Hydrotechnical Construction.

We expressed our appreciation to Professor Kronik for the interesting discussions with him. He spoke briefly with us about possibilities of his participation in a scientific exchange with CRREL. His interests are mainly in the kinds of problems we have been discussing, but also in geocryological investigations in general, including frozen soil mechanics, problems affecting industrial construction and road construction in the north, influence of development of the north on environmental conditions, and modern methods of field investigations such as airphoto interpretation and geophysical exploration. We are familiar with some of Ya. A. Kronik's writings, and received an excellent impression from our meetings with him.

Work at Lenin Library, September 3

Since our arrival in Moscow from Yakutsk on August 17, we had spent much of our spare time at the Lenin Library, first just figuring out how the system works, then finding papers of specific interest to us, and then trying to arrange to buy photocopies of some of the papers. On September 3 we spent the day in the library and finally succeeded in getting some of the copies. More were promised after our return from Leningrad.

LENINGRAD, SEPTEMBER 4 - 12

We traveled to Leningrad by night train on September 3, accompanied by V. Balobayev and our excellent interpreter Yu. A. Satbayeva. V.P. Mel'nikov joined us in Leningrad on September 7. On the weekend of 4-5 September we enjoyed some of the cultural attributes of the city and nearby communities, including the Hermitage Museum and the town of Pushkin.

For our stay in Leningrad, three visits to Lengidroproyekt and two visits to VNIIG were scheduled.

Visits to Lengidroproyekt September 6

We were received by L.K. Domanskiy, Chief Engineer, who conferred with us together with the following members of his technical staff:

A.F. Vasilyev	Deputy Chief Engineer
V.A. Susloparov	Chief Technical Division
Ya. E. Gluskin	Deputy Chief Engineer
V.G. Petrov	Chief Project Engineer
A.N. Demidov	Chief Project Engineer
A.L. Kuznetsov	Chief Project Engineer
A.N. Sizov	Deputy Chief Engineer
N.F. Krivonogova	Group Leader
A.P. Arsenyeva	Group Leader
Ye. A. Smirnov	Scientific Co-worker from VNIIG
N.F. Novikov	Chief Geologist

Domanskiy opened the program by telling us about Lengidroproyekt. He said the Leningrad Division is one of the oldest divisions within the Gidroproyekt organization. Lengidroproyekt designed the first hydroelectric station in the USSR, and is now working on its 50th station. Krasnoyarsk, the largest hydroelectric station in the world, was designed by Lengidroproyekt. Another huge project under construction now is Sayano-Shushenskaya, with a dam 240 m high and a generating capacity of 6400 MW. As for dams on permafrost, both Vilyuy and Mamakan Dams were designed by Lengidroproyekt, as well as Kolyma Dam, which is now under construction.

Lengidroproyekt, as an engineering organization, carries out all phases of the design of a water resources project. The design begins with preparation of a plan for development of a river, then proceeds through technical and economic studies of the project plan, and then in cludes a study of alternative designs. Lengidroproyekt also exercises engineering control during construction, and continues to participate in engineering questions during operation of the plant. Lengidroproyekt personnel also select any instrumentation and plan its installation. They study environmental conditions affecting a project and try to protect the environment from adverse effects. In recent years, Lengidroproyekt has designed and constructed projects in locations where permafrost is widespread. Nevertheless they do not have great experience in construction on permafrost.

Domanskiy proposed that, during our visits extending over three days, his engineers would acquaint us with four completed earth and rockfill dams, some of which were already in service for 10 years. The four dams are Vilyuy, and Irelyakh Dam and two dams on the Voron'ya River (near Murmansk) 60 and 80 m high, respectively. The latter two dams are not on permafrost, but the climate strongly influenced their construction. Domanskiy said they would also acquaint us with two dams now under construction on permafrost: Kolyma (more than 129 m high), and a 20-m dam being constructed as part of the Anadyr thermal electric station. The latter is in a permafrost region with very complex geologic conditions. Domanskiy said that Krivonogova would first outline for us the various stages in the development of a design for a dam on permafrost.

Krivonogova said that the special investigations for a dam in a permafrost region include an investigation of the existing thermal regime, examination of the cryogenic structure to serve as the basis for evaluating the properties of the soil and rock, and a prognosis of changes in the thermal regime and in the material properties. All of these factors depend upon the detailed climatic conditions of the site.

The methodology for designing a large dam involves several discrete stages. The first is the investigation of the river, including a permafrost survey of the region. The second stage consists of detailed site investigations. Boreholes and geophysical studies are used to determine the present thermal regime. The effects on the thermal regime of geologic conditions, the micro-landscape, talik zones, the heat of the reservoir, and the thermokarst structure are calculated. Special boreholes are used to study ground temperatures, and if samples of the frozen soil cannot be obtained in the boreholes, other means of investigation such as excavation of adits are used. This second stage, which is termed the "technical/economic base," also includes site selection. The Vilyuy No. 3 project is just now at the beginning of the second stage.

The third stage, termed "technical design," involves more detailed studies at the selected site. Here studies are made of the boundary between frozen and thawed soil, the depth of seasonal thawing and freezing, the temperature of the frozen soil and rock, the geothermal gradient, seasonal oscillations of temperature, and projected induced thawing of the permafrost. For investigation of the thermal regime, calculations are generally used, but physical models also are used to map the thermal field. Working drawings are not usually made at this stage, but when they are, the above studies are made in greater detail.

The fourth stage, "detailed design," includes more field investigations and studies of thermal regime of the subsoil. If the subsoil is frozen, its properties in the frozen state are determined. If calculations show that the subsoil will thaw, the properties are also determined in the thawed state. If complex geologic and thermal conditions are found, such as fragmented rock with high ice content, other institutes such as VNIIG, Permafrost Institute, and MGU are asked to assist in the studies.

Demidov then described the studies and design work performed for the Vilyuy Dam. He said that diamonds were reported in Yakutia as early as 1956. In 1958, to support the mining developments projected at Mirnyy, design investigations for the Vilyuy Hydroelectric Project were started (the first two generators went on line in 1967). Conceptual designs for a thermal electric station had been discarded earlier. Investigations on the Vilyuy River were started in 1958 and the site chosen the same year. It was found that dolerite rock was covered by 4 m of poor material at the center and by 15 m at the banks. Available local materials were stone, sand, and cohesive soil for the core, and all were frozen.

Transport of equipment and materials to the site was very difficult. The site is about 1500 km from the nearest railroad. A special port had to be used at Asitrova on the Lena River, from which the materials were carried to Lensk. They were carried by truck 350 km from Lensk to Mirnyy, and a road had to be built from there to Chernyshevskiy. During the summer, transport on the Vilyuy River was used for heavy equipment such as generators.

Vilyuy is one of the highest completed rockfill dams in the USSR. Higher dams under construction include Nurek (300 m) and Kolyma (126 m). The volume of Vilyuy Dam is about 5×10^6 m^3.

Demidov said that field and laboratory investigations were made for Lengidroproyekt during the design stages by VNIIG, Orgnogostroi (in Kuibeshev) and NIC (Gidroproyekt's Scientific Research Center). Demidov then went on to describe the cross section of the dam, most of which was familiar to us. He then talked about the core material, which he said was found in a near-surface layer only 0.6 to 1.5 m thick, under 0.3 m organic topsoil which was discarded. The limiting depth of excavation was the depth at which the percentage of material finer than 2 mm became equal to 55%. He said the coefficient of uniformity of the material (D_{60}/D_{10}) was about 800 to 1000. The material was compacted in the dam to 1.65 Mg/m^3, at a moisture content of 12-14%. The coefficient of permability of the core was about 10^{-6} cm/s and the angle of internal friction was about 27° to 28°. He said the core was constructed in winter, and it was considered acceptable to permit successive layers to freeze. The upper 2.5 m of the core was constructed of sand and gravel for protection against frost heaving. Demidov pointed out that no sizable dams had been built with frozen material in the USSR, and that the criteria for allowing the placement of core material were based on a test fill and visual inspection of test pits in the fill for ice segregation. Demidov said that under the downstream rockfill zone only a limited area was stripped to expose sound rock. The poorer quality material was removed only under the downstream one-third of the contact of the downstream rockfill zone with the subsoil. Demidov also spoke of the grouting. After constructing a concrete apron to protect against piping and to serve as a grout cap, contact grouting was performed to a depth of 3-4 m. About 8200 m of grout holes was drilled for contact grouting and the first stage (4 to 5 m depth) of curtain grouting. So far only one further stage of curtain grouting has been done, with a present maximum depth of the curtain of 10 to 15 m. (Note that earlier in this report we recorded a conversation with V.A. Medvedev, who gave a somewhat different account of the grouting.)

Demidov said that during construction three horizontal strings of thermistors were installed. They were placed at three different levels, about 20 m on centers and were extended upstream as far as the filters. Three inclined boreholes about 140 m apart also were also drilled into the core. Demidov displayed large-scale drawings showing temperatures observed in 1973 (similar to those shown in Biyanov's book - CRREL Draft

Translation 555). He said that the present temperatures differ little from those shown.

We asked whether Lengidroproyekt had foreseen the present thermal regime, and if so whether it would have prompted them to adopt a different design. Demidov said "no," they had not expected the downstream rockfill and its underlying subsoil to become filled with ice. He said that, having knowledge of this phenomenon, they have decided that at Kolyma not even the downstream one-third of the area of the rockfill zone will be stripped. We asked whether in the knowledge of the freezing brought about by air convection in the downstream zone, they would now be ready to build a high dam on poorer quality rock than that at Vilyuy. Demidov reminded us that the present thermal regime at Vilyuy only developed after eight years of operations; during earlier years one could not rely on such favorable thermal conditions developing.

We asked whether he thinks the pores in the rockfill are completely filled with ice. He thinks they are filled only up to the minimum tail water level above which they contain only atmospheric moisture introduced by air convection.

September 7. The discussions were concerned with two dams on the Voron'ya River and with the Irelyakh Dam. Vasilyev described the former. The Voron'ya River (Kol'skiy Peninsula) begins at Lov Lake, and flows about 100 km across tundra to the Barents Sea. The total drop (head loss) is about 150 m, mostly about midway along the river. In 1961 Lengidroproyekt prepared a development plan for construction of two dams, one of 80 m and the other of 65 m (20 km downstream).

At the 80-m dam, the reservoir volume is about 2 x 10^9 m^3. Bedrock at the site is granite under a layer of alluvium. It was decided to construct a rockfill dam, with a large central core protected by sand and gravel transition zones. Rock for the embankment is granite from required excavations, plus rock from a special borrow pit. Core material is from a glacial moraine, graded from about 13% larger than 100 mm, to 12% finer than 0.05 mm and 4% finer than 0.02 mm. The dry density of the core material in the pit was 2 Mg/m^3. The volume of the core is 1.8 x 10^6 m^3.

The most unusual feature of the dam is that (like about 20 dams in the USSR) the core was placed as a "puddled" fill. On earlier dams such fills had been placed only in summer, but in this case work was continued year-round. The builders first placed layers of transition material and rockfill. Then the core area was pumped full of water (heated in winter) and the moraine material was dumped into it. The average density achieved in the core was 2.1 Mg/m^3. It took two winters and two summers to complete the dam, which has been in operation since 1971 (see Hydrotechnical Construction, 1969, no. 8, and 1975, no. 1).

At the downstream site no moraine soil was found, but gravelly sand was abundant. The entire dam was built of sand with upstream slope of 2:1 and downstream slope of 2:1 with three berms. A steel sheet pile cutoff was placed in the embankment as the fill was raised. The interlocks were caulked.

At the right side of the valley an alluvium-filled channel was found to a depth of 60 to 80 m. The upper portion of the alluvium had a coefficient of permeability of 80 m/day. Steel sheet piling was installed to a depth of about 22 to 23 m as a partial cut-off across the buried channel. At the left side of the valley a small trench was excavated in the rock, filled with concrete, and grouted.

At the right side of the river bed, a 14-m deep channel was found in the rock. A diversion conduit was built, and cofferdams were placed around the area to excavate the channel filling. But it was impossible to pump out the area because of high inflow through a layer of coarse gravel. So the builders put two lines of steel sheet piling across the channel, constructed a grouting gallery above the piling, and grouted the gravel between the two lines of sheet piling. The work then proceeded without further difficulty. The sand fill was placed year-round. It was placed quite dry in 0.5-m layers and compacted with rollers and trucks.

The Voron'ya River dams were of marginal interest to us because they were not on permafrost, and no analyses or observations of thermal regime were made. We were to hear next from Kuznetsov regarding the Irelyakh Dam. We were already quite familiar with this dam but hoped to gain some new perspectives.

Kuznetsov said that the chief project engineer who was in charge of Irelyakh has retired. Kuznetsov's main task currently is the design of a dam at Anadyr, but he is familiar with Irelyakh because he is also now designing an enlargement (raising) of the dam. Kuznetsov said Lengidroproyekt designed Irelyakh Dam in 1961. It was to be the first time a dam of such size (20 m) would be built on permafrost that thawed and then was artificially frozen.

The climate at the site (Mirnyy) is similar to that at the Vilyuy Dam: average annual temperature -8.2°C, minimum temperature -60°C, maximum temperature 35°C, temperature of permafrost (at depth of zero seasonal amplitude) -2 to -3°C. The subsoil consists of 10 m of clay loam (suglinok) with about 60% ice. Beneath this material is a clay with sand and limestone (possibly marl?), similar to materials we saw at the site of Vilyuy No. 3. The ice content of this material is about 10-25%. Under the river channel a talik was found to a depth of 8 m.

Investigations showed that, if the subsoil thawed, a layer of embankment material would cause settlement equal to 30% of its thickness. This finding was obtained from field measurements of thaw settle-

ment of heated plates with a 1-m^2 loaded area. Similar results were obtained in the laboratory with a higher load. Consequently the designers considered removing the suglinok, but as it would have proven too costly and time-consuming, they decided to design a frozen dam. They decided such a dam could be built in two years.

Lengidroproyekt had thermal calculations made by Bogoslovskiy, and 1:100-scale models for thermal studies were made by VNIIG. From these studies it was decided the central and downstream portions of the dam would be kept frozen, while the upstream portion and the subsoil to some depth would be permitted to thaw. The design life premise for this scheme was 40 years. As it was expected the upstream portion would experience some settlements, the slope was made flatter.

The thermal calculations did not include any effect of seepage. They did include the effect of artificial cooling as the designers knew it would be necessary, from earlier experience on smaller dams. It was decided to use one ventilator header for each group of 20 to 30 freezing pipes. It was considered that there would be danger of condensation filling the pipes with ice if the temperature rose above -15°C. Special boreholes were made to measure the temperatures during operations. The 19 boreholes were in three lines, oriented upstream to downstream. Measurements were made also of settlement of the embankment, using observation points only on the surface of the dam. In 1970-71 the cooling system was not operated, after having been in operation each of the preceding six winters. Temperature measurements showed that the system must continue to be operated, and each succeeding winter the cold air has again been circulated through the freezing pipes. The power requirement is about 200 kW, over a period of about 1.5 months each winter.

Kuznetsov said that they plan to raise the dam about 1 m and put in a gated spillway so that the water level will be raised about 1 to 1.5 m. There is some question whether continued thaw beneath the spillway should be permitted. One scheme being considered is a form of hydro-insulation (a seepage cut-off?) to stop seepage through the spillway into the subsoil.

We asked whether the observed temperatures agree with those predicted by calculations and modeling. Kuznetsov said the calculations made in 1962 showed that it would take much longer to reach a stable temperature condition than it actually did. Recently Shugayeva of the Kraznoyarsk branch of VNIIG made a better calculation; her method is one of the best now available. Shugayeva made a comparison of the calculated and observed temperatures at Irelyakh, much as Mukhetdinov did at Vilyuy. A new method of calculation has recently been used for the Anadyr Dam. It is a modification of Bogoslovskiy's method introduced by his student Semyenov.

September 8. We asked Kuznetsov about the piezometers used in dams on permafrost. He said they are heated, usually electrically. He said details of piezometers are worked out in Moscow by Gidrospetzproyekt.

Gluskin then talked to us about the Kolyma Hydroelectric Station, now under construction about 500 km north of Magadan. He said that the station is needed to support the mining of precious metals. The environmental conditions are more rigorous than at the Vilyuy station:

	Avg. annual temp. (°C)	Temp. at depth of zero seasonal amplitude (0°C)
Vilyuy	-8	-2 to -6
Kolyma	-12	-4 to -8

The geologic conditions also are worse than at Vilyuy, which has diabase and dolerite with little cracking. Kolyma has granite that is hard in core samples but in the mass it has many cracks. At the surface there are 3-4 cracks per meter, but at depth they are more widely spaced. The cracks near the surface are about 2 cm wide, and some are filled with ice throughout. In the river channel there is a through-talik, which has been verified by geophysical testing, boreholes, and temperature measurements. At the left bank, the granite is frozen to a depth exceeding 100 m, while at the right bank the depth of permafrost is about 50 m.

The dam will be of rockfill, with height of 126 m. The diversion conduit is planned to be placed at the right bank, which slopes more gently. On the left bank where the river channel is situated, the lower part of the channel will be used for a low-level power intake, while the upper part will be used for a spillway approach channel. As the granite has many cracks, it was difficult to design the contact between the dam and the bedrock. Whereas at Vilyuy Dam it was planned to grout as thawing proceeded <u>during operation</u> of the plant, at Kolyma this plan is not possible. The coefficient of permeability of the upper 20-30 m of rock is 120 m/day (50-100 times that at the Vilyuy Dam site), as determined by pumping tests. With such pervious rock it was decided the grouting must be done before the reservoir is filled.

Accordingly the designers decided to pre-thaw the rock. Experiments were made at the site, with a number of boreholes spaced 7 m apart on a grid pattern, and drilled to 40 m depth. River water was pumped in during the summer, when the water temperature was about 10°C, and the rate of thawing was found satisfactory. Grouting tests were also made at that time.

For the Kolyma Dam it was decided to use a conventional central core type of cross section. (Details of the dam are given in *Trudy, Gidroproyekt* no. 34, 1973.) For core material a gravelly clay loam

(suglinok) similar to that at Vilyuy is available in a surface layer several meters thick. In some places it thaws in the summer to a depth of 1.5 m. Methods of increasing the depth of summer thaw are being studied, including removing the vegetation, or covering the surface in winter with insulation or heating panels.

Diversion cofferdams are needed to a height of 45 m. Instead they will be built to a height of 60 m and the additional storage capacity will be used to generate electricity. Therefore a low-level intake is needed for use during this period. This arrangement will produce electric energy in 1980, three to four years before the dam is completed. Also the dam itself can be built in the dry, and there will be time to decide how to pre-thaw the subsoil, whether by pumping in water through the grouting gallery or from the ground surface. This plan requires that the cofferdam be designed to contain the 200-year flood. Usually a diversion cofferdam would be designed for the 100-year flood, or if made safe to withstand the effects of overtopping, the 10-year flood. For Kolyma the 2.5×10^6-m^3 cofferdam will be built from October through May, and construction of an impervious zone is impossible in that time. Consequently three layers of 0.02-mm polyethylene will be used to prevent seepage.

The expected time for construction of the central part of the dam is 3 to 4 years; its volume will be $14 \times 10^6 m^3$. Transition zones next to the core of suglinok will be a gravelly sand, and then either a broken rock (shebin) or a coarser-grained sand and gravel.

Gluskin called to our attention that the rockfill will be placed without compaction. The coefficient of permeability of the core material is about 10^{-7} to 10^{-6} cm/s, and consequently the core will consolidate slowly. The rockfill is expected to consolidate more rapidly, and Gluskin said that they have consequently decided not to bother to compact it.

We asked whether the designers expect that the downstream rockfill will become filled with ice by air convection. Gluskin said they expect the lower part, below tail water level, to be ice-filled, but they don't know about the upper part. The climate is humid and there are monsoon rains. We asked whether it is true that the downstream rockfill zone at Khantaika is filled with ice. Gluskin said they are not sure yet because there are no tests. He said on the other hand that the thermistors at both Vilyuy and Khantaika show the temperature below tailwater level is not greatly dependent on air temperature, while thermistors at higher level show dependence on air temperature. Gluskin said that at Kolyma, the downstream slope will be covered with broken rock (shebin) and finer material to reduce air convection. Also, at Kolyma, because the downstream rockfill and subsoil are known to be frozen, the topsoil will not be stripped.

We asked why the Lengidroproyekt designers selected a central core instead of an inclined core. Gluskin said they had surveyed world practice, which shows:

Dams over 100 m	central core	35	(9 in rigorous climate)
	inclined core	7	(2)
Dams 80-100 m	central core	47	(2)
	inclined core	14	(1)

We asked whether any thermal calculations were made. Gluskin said that calculations were made to predict the condition of the core (they do not wish the core to be frozen because it might be brittle). All calculations were made by VNIIG's Kraznoyarsk office. The results, which include the effects of seepage, show that the 0°C isotherm will be in the downstream transition zone. Gluskin made reference to a paper by Gluskin, Losev, Petrov, and Frumkin, in Hydrotechnical Construction, 1974, no. 8.

Gluskin then explained to us some of the conditions found at the site of the planned Ust'-Botuobiya Hydroelectric Station (Vilyuy No. 3). It will be located on the Vilyuy River about 100 km downstream from Chernyshevskiy. Gluskin said that Lengidroproyekt is now beginning the second stage of studies of the project, the technical-economic base, which they will finish in 1977. So he said that just now they have only general concepts for the project, which will have a dam about 65 m high. A talik 80 m wide and about 50 m deep was found under the river. All the concrete structures, including a combined spillway and powerhouse, are proposed to be located in the river section, over the talik. Rock-fill dams are planned on both sides of the central concrete structure. On the right bank all the poor materials will be removed because this will be the site of the diversion channel. The channel may be excavated to 25-30 m, but perhaps an axis can be chosen that will limit the excavation to 20 m. They will try to set the axis such that there will be no excessive settlement even though high-ice-content soil may remain.

On the left bank, poor soils with high ice content (up to 50%) are found to considerable depth, perhaps 25 m. It has not been decided whether to remove all this poor soil, or to construct the dam with excess height and let it settle. The designers are also considering the possibility of using artificial cooling for the project, but it appears that the unfrozen variant would cost 10% less, even if it included removal of the high-ice-content soil at the left bank.

Beneath the high-ice-content strata are soils with an ice content of 5-7%. Their removal is not considered necessary, and as a general rule only material with an ice content greater than 10-15% would be considered for removal. Also, the rock below the talik at the site of the spillway/powerhouse is practically impervious. Consequently, no consideration is being given to pre-thawing below the talik.

Kuznetsov again addressed us, this time describing the investigations for a water supply dam now under construction at Anadyr, near Anadyrskiy Bay on the Bering Sea. The dam is part of the development of the Anadyr Thermoelectric Station. The dam will be 1300 m long and 16 m in height and will incorporate at its upstream toe an existing smaller dam.

The climate at Anadyr is very rigorous, and geologic and permafrost conditions are difficult. The average annual temperature is -7.4°C, and minimum and maximum air temperatures are -47° and 27°C, respectively. Summers are short and cold, with average temperatures of 5.7°C, and with frequent rain. In winter the average temperature is -22°C. There are many storms and heavy snow in winter, with winds to 40-50 m/s. In the subsoil for the dam, under 0.5 m of topsoil, are 9 m of successive layers of frozen sandy and gravelly soil with ice content of 30-80%. Thaw consolidation of these layers under 1 m of embankment would be about 30-50 cm. Beneath these high-ice-content soils is frozen clay loam (suglinok). A talik is found under the river channel, extending to a depth of 6 to 7 m.

The first design for the dam called for a central core of suglinok, an upstream shell of gravelly soil, and a downstream shell of rock fill. No artificial cooling of the core or subsoil was planned. A cutoff trench was to be excavated 9 m deep, through the talik and the high-ice-content soils. This design was the subject of thermal calculations by Professor Bogoslovskiy and by the Siberian Division of VNIIG, at Kraznoyarsk. Kuznetsov sketched for us the calculated positions of the 0°C isotherm at 1 year and 25 years after construction, approximately as shown in Kuznetsov's paper, CRREL Draft Translation TL 659. At one year the position of the projected 0°C isotherm would leave the entire downstream filter and rock fill shell unfrozen. The projected 25-year 0°C isotherm, on the other hand, showed the core would be almost entirely frozen.

Recognizing the disadvantage of a cross section that would have a partially unfrozen core for several years, Lengidroproyekt decided to consider a variant with cooling devices, and undertook a study of the effectiveness of vapor/liquid thermal piles (similar to Long piles). Seven piles were installed near the Anadyr site in a lake 3 m deep beneath which there is a talik about 20 m deep. In winter, working from the lake ice, they made boreholes 15 m deep and installed the piles in a line with center to center spacing of 1.5 to 3 m. The work was done during a snowstorm, with air temperature about -35°C. On March 13 (1973) Freon was put in and the piles started to function. At that time the temperature in the talik was +3° to 4°C. After 45 days the soil was found to be partially frozen. The average air temperature was about -12°C. Where the pile spacing was 2 m, a frozen wall 1.2 m thick had developed. Where the spacing was greater, the thickness was about 1 m but some gaps were found. Except for these gaps, a frozen wall had

formed to the bottom of the piles, even though the piles did not extend to permafrost. The following October the piles were activated again, and by the end of May (1974) the thickness of the frozen wall was 4 m. Calculations of the effects of the thermal piles were made by an institute in Leningrad, using the hydraulic integrator, and the results were very close to those actually obtained in the field test.

The results showed that the talik could be frozen with thermal piles, and that the cooling effects could be calculated for different air temperatures and/or properties of the soils. Accordingly, Lengidroproyekt redesigned the dam to take advantage of the cooling effects of thermal piles. According to the new design, no cut-off trench is to be excavated through the talik and ice-rich soils; instead only 0.3 to 0.5 m of topsoil will be removed. The dam will be similar in cross section to the earlier design except the relatively costly suglinok will not be used for the core. Instead, the "puddled core" method used at the upstream site on the Voron'ya River will be adopted. The "puddling basin" will be lined on the inside with finer soil to keep the water from draining out. The core material will be broken rock with about 30% of natural soil finer than 2 mm. It will be placed in water and thus initially will be fully saturated. On completion of the embankment, thermal piles will be installed to a maximum depth of 26 m. The spacing of piles will be 2 m in the central part of the dam, and 3 m in the left and right abutment areas. On the left and right banks the depth of the piles would be only as needed to reach the relatively impervious suglinok soils.

In the analysis of the thermal regime it was assumed that the dam would be constructed to a certain height during the first summer, at air temperatures of +5 to 8°C. During the following winter some freezing would take place, but an unfrozen zone would remain in the central portion of the dam at some depth below the top of the first summer's construction. After completion of the embankment in the second summer, winter freezing would again occur, leaving a second central unfrozen zone at a higher level, separated from the first by a zone of frozen material. This would be the initial condition during the installation and activation of the thermal piles. The initial conditions would, of course, be more favorable if the dam were constructed continuously through all seasons, and would be even more favorable if the construction period should be three years instead of two.

The thermal analysis of the dam with cooling devices shows that after two years the central and lower parts of the dam will be frozen, and that below the dam the permafrost will be stable. After 25 years the central part of the dam will be completely frozen, and the subsoil under the dam centerline also will be completely frozen.

The new design was judged by Lengidroproyekt and Minenergo to be superior to the original design, and construction according to the new scheme is now in progress (1976).

Three published papers were cited by Kuznetsov in reference to this project: Hydrotechnical Construction, no. 5, 1976 (investigation of thermal piles); Trudy, Gidroproyekt, no. 40, 1974 (analysis of the cooling system); and Trudy, Gidroproyekt, no. 51, 1976 (description of original design of the dam).

Visit to VNIIG September 9

We were received at VNIIG by R.V. Krasovitskiy, Deputy Director for the Scientific Division, who conferred with us on September 9 and 10 with the following members of his staff:

I.N. Sokolov	Chief, Laboratory of Thermal Investigations of Ice
Ye. A. Smirnov	Chief, Far Northern Dams Group-Complex Laboratories of Earth Structures
Sh. N. Plyat	Doctor of Technical Sciences and Scientific Group Leader
N.F. Shavelyev	Senior Research Worker
V.A. Turchina	Senior Engineer
N.A. Mukhetdinov	Chief, Engineering Thermal Physics Branch, Siberian Division of VNIIG

Krasovitskiy introduced his staff members and said that he understood that we were interested in frozen ground. He said in fact VNIIG does not study the properties of frozen ground, but perhaps some of their hydrotechnical work would interest us. We asked whether VNIIG makes the analysis of thermal regime for all dams on permafrost designed by Lengidroproyekt. Krasovitskiy said "yes," VNIIG does make all such analyses, but other institutes make the analyses too. He then asked Smirnov to summarize VNIIG's work on thermal regime, with particular reference to Vilyuy Dam.

Smirnov said VNIIG's first work on thermal regime of structures in the North was in 1937, when they made a preliminary design for a 60-m high rockfill dam with a metal screen (seepage barrier) for a site in the region of Kolyma. They designed a system of horizontal tubes in the base of the dam for circulating brine coolant. Later, VNIIG helped Teploenergoproyekt design the well-known Dolga River Dam, which was built in 1942. VNIIG worked during the 1940's to develop methods of analyzing thermal fields, and methods of cooling to freeze the ground. By the early 1950's they had already worked out the theories of physical modeling, which were published in their journal, Izvestiya of VNIIG. By the 1960's when they began to analyze the Irelyakh and Vilyuy Dams, they already had a scientific base for making thermal calculations. They could make preliminary analyses and, with the help of physical modeling, could predict the thermal regime.

For the Irelyakh Dam they made a 1:75 scale model, and investigated the thermal regime as it would develop during 15 years of operations

(Smirnov showed us the isotherms determined with the model). The modeling conditions included an assumed constant temperature of -3°C in the permafrost subsoil, and a temperature of +4.7°C at the bottom of the reservoir. On the downstream side, the surface temperature was taken as the average of the air and permafrost temperatures. The model was made of natural soil. The conditions were such that 1.5 model hours equaled 1.0 prototype years. Seepage was not considered because it was planned to fill the reservoir only after the dam became frozen.

At the same time, a mathematical analysis of the freezing of the soil was made. The analysis was one-dimensional, by a method similar to that described by Tsytovich, Ukhova and Ukhov (CRREL Draft Translation 435). At that time a prediction of the thermal regime was also made by the Permafrost Institute, using the hydraulic integrator. The initial conditions for the three methods of predicting the thermal regime were not the same, so the results were not identical. Smirnov showed us the results predicted by the physical model studies and the one-dimensional mathematical analyses, which were generally similar. He said that the prediction by the Permafrost Institute also was similar.

Smirnov said that a prediction of the thermal regime for Vilyuy Dam could not be made analytically because at that time they did not have a method for analyzing rockfill dams. So they made a model, in the case of this larger dam to a scale of 1:200, because of space limitation of the available cold chamber. The model could not be made of natural material, and the coarse material had to be modeled by small stones. Therefore the results of the analysis, which showed that the lower part of the dam and foundation would be frozen, were quite different from those actually observed later in the dam. But the model showed correctly that the screen (inclined core) would be thawed, and the general pattern of the temperature conditions was reasonable. It was, of course, impossible to reasonably model the effects of air convection in the rockfill zone.

Smirnov showed us drawings of the dam cross section, depicting the current temperature field determined by temperature sensors installed in the screen (inclined core) and downstream rockfill zone (similar to Fig. 5-11 of "Dams on Permafrost," G. F. Biyanov, CRREL Draft Translation 555). Other drawings showed amplitudes of seasonal temperature changes at various points in the downstream rockfill zone. We recorded the amplitudes at several points:

Location	Seasonal amplitude (°C)	Remarks
One third of way up from base	6-7	Amplitude less toward the screen
Midway up from base, near downstream slope	30-35	Much air convection here
Two-thirds of way up, near screen	5-6	Summer temperatures are positive
Within screen (inclined core)	0-1	The portion of screen that was built frozen has thawed, but is now stable.

Smirnov said he believes that the pore spaces are filled with ice only in the lower part of the downstream rockfill zone, which is affected by tailwater. At higher levels, rainwater freezes as it percolates downward, but subsequently it sublimates and the pores are filled with air. We asked if the pores would fill more rapidly in a region of higher relative humidity; Smirnov said he thinks the buildup of ice is related more to rainfall than to relative humidity.

Dr. Plyat then spoke to us on the subject of calculations of thermal conditions in dams and their foundations, a subject that he said is given much importance in VNIIG's work. He gave us a copy of his book "Calculation of Temperature Fields in Concrete Hydraulic Structures" (CRREL Draft Translation 615). Plyat referred to the use, by a group of researchers at the Siberian Division of VNIIG, of an electronic computer to calculate the thermal regime of dams. Plyat was scientific leader of that group of researchers, and referred specifically to the papers of Mukletdinov, Shugayeva, and Pridorogin. Methods were developed for three problems:

1. Non-steady thermal fields in earth dams in areas without phase change. Such areas include relatively dry zones of rockfills or stony soils, as well as frozen zones in which temperatures do not rise above 0°C.
2. Freezing and thawing of earth dams without special cooling devices, and of tailings dams, connections to abutments, reservoir bottoms, etc.
3. Calculation of the thermal regime during the process of construction of embankments in layers, including the change in the thermal field during construction.

Numerical methods are used in the solution of all these three problems, using the technique of finite differencing. Algorithms were developed for the electronic computers in use in the USSR, and the programs are written in ALGOL 60. Thermal fields can be calculated in single- and multi-phase masses including soils of differing thermal properties and conditions of changing geometric configuration during the

process of construction. The calculations account for climatic changes, engineering/geologic conditions, snow cover, internal temperature fluctuation, soils of differing ice content, existence of zones of frozen and thawed soil, and various processes of natural and artificial cooling. Either rolled-fill or hydraulic-fill construction methods can be accounted for.

Dr. Plyat mentioned his group's thermal studies of the dams at the hydroelectric stations on the Irelyakh and Sytykan Rivers and the thermoelectric station at Anadyr. The objective of the calculations for the Anadyr Dam was to determine the thermal regime of a dam of the frozen type with natural cooling. For the Sytykan and Irelyakh sites they sought the thermal field as it would be developed by the time the dams commenced operation to define the conditions affecting the thermal regime of the spillway channel. At Irelyakh the calculated temperatures were compared with those measured in the dam, and were published in the journal, Izvestiya of VNIIG, no. 93. The calculations were based on the Fourier conduction equation, and took into account the phase change. Convective heat transfer, by seepage, was not considered.

Plyat said that a more complex problem was confronted in connection with calculation of the thermal regime of rockfill dams. For this problem, which would be described in detail by Mukhetdinov in our meeting on the following day, the main equations of the process first were formulated. The rockfill in some areas would at times be dry, and it was necessary to account for convective heat transfer by moving air, and in some cases by water as well. Solutions of the equations were developed and can be applied to simple practical engineering problems. For important structures, numerical (finite difference) methods have been used. The equations account for anisotropy of both thermal and hydraulic conductivity in the rockfill zone of the dam.

Plyat said the thermal field in the downstream rockfill zone of Vilyuy Dam was analyzed in detail and was compared with in-situ data. The analysis considered heat exchange at the surface of the rockfill affected by environmental conditions, engineering-geologic and frost conditions, geometric configuration of the dam and the nonlinearity of free air convection in coarse rockfills.

Dr. Plyat observed that the two methods of analysis, developed for earthfill and rockfill dams, respectively, complement each other. He said the rockfill analysis method can also be applied on earthfill dams, while some of the results from earthfill dams, dealing with phase change, can be applied on rockfill dams. He referred to the papers of Mukhetdinov and Shugayeva, published in the following editions of Isvestiya of VNIIG:

No. 90 (1969)	Mukhetdinov	(CRREL Draft Translation 586)
No. 96 (1971)	Mukhetdinov	(CRREL Draft Translation 580)
No. 96 (1971)	Shugayeva	
No. 107 (1975)	Mukhetdinov et al.	
No. 111 (1976)	Shugayeva and Kuznetsov	

Sokolov then spoke to us about his work related to the effects of ice on hydraulic structures. VNIIG apparently makes extensive investigations of ice regime, thickness of ice, thermal regime in reservoirs, ice action on structures, bearing capacity of ice covers, control of frazil ice, problems of ice adhesion to trash racks and conduits, etc. Sokolov told us that ice formed in the winter is used to cool thermoelectric plants in summer. He also said SNIP (Construction Standard) II-57-75 contains calculation methods for thermal regimes in reservoirs.

Shavelyev summarized his investigations of materials for use as antiseepage barriers in dams. His studies have concentrated on materials other than soils, such as polymers, portland cement concrete, and asphalt concrete. He has recently made a special study for Ust' Botuobiya Dam (Vilyuy No. 3) and recommended use of asphalt concrete for the diaphragm. Shavelyev believes that asphalt concrete will find extensive future use in cold regions as seepage barriers in earthfill and rockfill dams.

September 10. V. Balobayev and V. Mel' nikov of the Permafrost Institute were well aware of our great interest in the work of N.A. Mukhetdinov of the Siberian Branch of VNIIG in Kraznoyarsk. Through their efforts and with the cooperation of the management of VNIIG, Mukhetdinov had traveled from Kraznoyarsk to Leningrad (about 4000 km) to confer with us. We had an interesting session on September 10, in which Mukhetdinov talked to us about his work in analyzing the thermal regime of rockfill dams, including air convection in the rockfill zone.

Mukhetdinov said that natural convection in bodies was studied long ago. In the Soviet literature the problem of thermal exchange between a vertical surface and atmospheric air under natural convection is already solved. But these solutions cannot be used for rockfill dams because the rockfill is of a composition that is variable in space, and is what might be termed a "statistical" mixture. Mukhetdinov said that therefore he did not take into account the micro-discontinuities of the rockfill, and he used average parameters for the air that moves in the pores. The pore medium is considered continuous with many channels in all directions in communication with atmospheric air. Hence, he could use all the methods of the mechanics of continuous media.

The main cause of movement of pore air is the inequality of its density. At different locations within the rockfill the density of the pore air can be quite different. This process follows Archimedes' principle. Mukhetdinov first thought that the movement of air follows Darcy's law. With the rockfill considered a continuous medium and all pores filled with air, the air can be moved by a potential. Mukhetdinov considered only the body forces developed in accordance with Archimedes' principle. He wrote the equilibrium equation given in his paper in Izvestiya of VNIIG, vol. 90, 1969 (CRREL Draft Translation 586). He used Poisson's equation to obtain the necessary function of air velocity.

Mukhetdinov then described the mathematical developments, approximately along the lines of CRREL Draft Translation 586. He also referred to further theoretical work based on the assumption of nonlinear air flow, in which the air velocity is taken as proportional, not to the gradient (per Darcy's law), but to the second power of the gradient. For this work he referred to his paper published in Izvestiya of VNIIG, vol 96, 1971 (CRREL Draft Translation 580).

Mukhetdinov said the validity of the equations was tested for the conditions at Vilyuy Dam (see Draft Translation 586). The equations were solved by the method of finite differences, using initial conditions measured at Vilyuy Dam in 1967. Coefficients for the calculations were taken from material properties observed during construction of the dam. The air temperatures were taken as monthly averages. Comparison of calculated temperatures with those measured in situ showed differences of about 4°C near the outer surface of the rockfill and 1-2°C near the inclined impervious zone. Mukhetdinov said these differences can be explained by the daily temperature oscillations, which for this problem are very significant.

By the calculations it was found that deep freezing beneath the downstream rockfill zone at Vilyuy Dam is possible. Calculations were made for summer conditions, showing that an inversion of air flow takes place in the downstream rockfill zone. Warm air circulates downward through the rockfill and outward at the toe. In spring the temperature is about -25°C, and at the toe lower. The upper part becomes thawed for about 30 m. One of the factors that favorably influences the general thermal condition of the dam is that positive temperatures are stable near the inclined impervious zone at the top. This stable warm air impedes the inflow of cold air at the crest.

Mukhetdinov said the velocity of pore air is fully defined by the differences in temperature, but it is not always known when the linear law (Darcy) is not applicable. Since the linear law is not valid when the temperature difference is great, he developed methodology for nonlinear flow as well (see CRREL TL 580). Comparison of the two methodologies shows that consideration of nonlinearity of air flow decreases the rate of change of temperature in the rockfill. Mukhetdinov said that later he considered better methods of getting design parameters for large-pore-volume media such as rockfills. He referred to Izvestiya of VNIIG, vol 107, 1975. He said that initially the air velocity increases, but then approaches a constant value. He said experimental data also confirm that the velocity becomes stable with time.

He said that among his current interests is the influence of water and water vapor on the development of the thermal regime in rockfills. He said air convection had caused the ice content of the rockfill at Vilyuy Dam to reach 40 kg/m^3, while at Khantaika Dam some of the rockfill, with a porosity of 30-35%, has become ice-filled (implying about 300 kg/m^3 of ice). We asked about the cause of the difference. He said

that the prevailing winds at Khantaika Dam deposit three times as much snow on the slope as on a horizontal surface. Since snow is a dynamic medium, its effect on convective heat transfer changes with time. Also at Khantaika Dam the annual precipitation is 500 mm, while at Vilyuy Dam it is only about 250 mm.

MOSCOW, SEPTEMBER 13-15

After spending the weekend in Leningrad, we returned to Moscow by train on Sunday night September 12. September 13 and 14 were devoted to arranging for travel back to Hanover, and to searching for several technical journals, books and papers that had been referenced in our meetings. We searched without success through many bookstores. We did succeed in getting copies of several papers from the Lenin Library.

By this time it had become clear that our gracious hosts V. Balobayev and V. Mel'nikov had not succeeded in getting authorization from their government (Academy of Sciences and Ministry of Foreign Affairs) to accompany us back to Hanover. We left Moscow on September 15 with the hope that they would be permitted to come to Hanover within about one month. Evidently such permission was not obtained, and in November we received a cablegram postponing the visit until the following spring. We do not know whether further attempts were made to obtain authorization; at any rate the visit has not taken place.

Appendix A. PROTOCOL OF DISCUSSIONS

between representatives of the Cold Regions Research and Engineering Laboratory (CRREL) of the Corps of Engineers, USA, and the Permafrost Institute of the Siberian Branch of the Academy of Sciences of the USSR.

Discussions to implement and prepare a draft program of scientific cooperation were held at Hanover, New Hampshire, 16-17 June 1976.

Background: (a) In a letter, dated 19 June 1975, the Soviet Academy of Sciences in response to an inquiry from the Technical Director, CRREL, suggested the implementation of a cooperative agreement on the basis of an "Agreement on exchange of scientists between the National Academy of Sciences of the USA and the Academy of Sciences of the USSR."

(b) The National Academy of Sciences of the USA responded with a detailed proposal, dated 10 October 1975, for an initiation of the cooperation by receiving two scientists from the Permafrost Institute for a two-month period and in turn sending two CRREL research engineers to the USSR for a similar period.

(c) In a letter, dated 9 April 1976, the Academy of Sciences of the USSR endorsed a cooperative agreement in principle and expressed its willingness to begin an implementation in the summer of 1976 and to negotiate a program of further cooperation.

(d) In a letter, dated 3 June 1976, the National Academy of Sciences of the USA endorsed the cooperative agreement and suggested direct discussions between CRREL and the Permafrost Institute for further cooperation.

(e) Two representatives from the Permafrost Institute, Dr. P.I. Mel'nikov and Dr. F.E. Are visited CRREL for this purpose on 16-17 June 1976 after arriving in the USA as part of a Soviet delegation studying pipelines in permafrost.

Participants in the discussions from the US side:

Colonel Robert L. Crosby, Corps of Engineers, Director of CRREL
Dr. D.R. Freitag, Technical Director of CRREL
Dr. A.V. Assur, Chief Scientist, CRREL
Dr. K.F. Sterrett, Chief, Research Division, CRREL
Mr. A.F. Wuori, Chief, Experimental Engineering Division, CRREL
Dr. G. Ashton, Chief, Snow and Ice Branch, CRREL
Mr. E. Lobacz, Chief, Construction Engineering Research Branch, CRREL
Dr. G.K. Swinzow, Research Geologist, CRREL

Other CRREL staff members participating in part of the discussion were:

Dr. M. Mellor, Mr. P. Sellman, Mr. T. Johnson

Participants in the discussion from the Soviet side:

Dr. P.I. Mel'nikov, Director of the Permafrost Institute of the Academy of Sciences of the USSR
Dr. F.E. Are, Division Chief, Permafrost Institute

Itinerary and description of activities

Wednesday, 16 June 1976

0945 - Arrival Lebanon airport
1015 - Arrival CRREL
1000-1230 - Adoption of agenda and preliminary discussions
1230-1400 - Break and private discussion
1400-1600 - Discussion of specific proposals

Thursday, 17 June 1976

0830-1130 - Discussion of proposals and preparation of protocol
1130-1400 - Mutual discussion with CRREL staff members
1400-1600 - Finalization of protocol
1600-1700 - Tour and discussion of new facilities at CRREL
Evening-Free - Discussion of items of mutual interest

Friday, 18 June 1976

0830 - - Depart Hanover, New Hampshire

Summary of Discussions

Detailed discussions in depth were held with the purpose of implementing the cooperation in the most efficient and mutually beneficial way. At first the corresponding background was reviewed, clarifying mutual intentions and any unclear question of principle or administrative nature.

Since the specialists to be exchanged are working scientists and engineers, it was agreed that the end-products of the exchanges will be reports on the selected study topics, which will be printed and made available to both sides.

The originally suggested date for the departure of Messrs. Johnson and Sayles (1 July) is now considered impractical but a departure for the USSR in the middle of July is feasible. A visa request would be made for Moscow, Leningrad, Krasnoiarskiy Krai and Yakutia. The American specialists would like to visit the following:

1. Hydroproyeckt in Moscow (G.F. Biianov) and in Leningrad (Glutkin, Ziskovich).

2. Moscow Institute of Construction Engineers (N.A. Tsytovich).

3. Geological Institute of the Ministry of Geology USSR, Moscow (S.E. Grechishchev).

4. Institute for Foundations and Underground Construction, Gosstroi USSR, Moscow (S.S. Vialov).

5. Viliuy Hydroelectric Station.

6. Khantaka Hydroelectric Station.

The Soviet side will endeavor to get in touch with other agencies to arrange a suitable schedule, including visits to institutions not under the jurisdiction of the Academy of Sciences, but cannot promise at this time how successful they will be in this effort. The Soviet side is well aware of our interest in dams and will make any possible arrangement within their jurisdiction, and hopes to make arrangements with such principal specialists as Ing. Biianov at Gidroproekt and others.

As specified in the agreement between the Academies the Soviet side will provide for expenses of the U.S. team upon their arrival in Moscow.

Personal data on Messrs. Johnson and Sayles had been submitted previously. If it is necessary to send an alternate sufficient advance information will be given.

Members of the Soviet team will be the following:

Mel'nikov, Vladimir Pavlovich, head of the geophysical laboratory for the study of permafrost

and Balobaev, Veniamin Tikhonovich, head of the geothermal laboratory for the cryolithozone

Personal data were given for administrative processing. If it would become necessary to send an alternate, sufficient advance information would be given. Tentative arrival is expected in the middle of September. CRREL will provide for expenses of the Soviet team upon their arrival in New York, in exchange for similar privileges in the USSR as specified in the agreement between the Academies.

The Academy of Sciences of the USSR would appreciate that their team be given an opportunity during their visit to work in their special fields which are as follows:

Mr. Mel'nikov is involved in geophysical studies of permafrost using the entire range of available methods. In particular, work is being done on induced polarization. Contour maps of available resources are the desired end products, as well as the detection of ice wedges and massive ice formation. Of particular interest is the determination of ice

content in frozen soils and permafrost. Efficient methods are needed to provide proper design information for engineers (which also is a goal being pursued by CRREL on these same topics).

It would also be most helpful if CRREL research on the determination of unfrozen water content in frozen soil could be expanded to provide information on engineering properties of frozen soils.

A comparison of US and Soviet methodologies in these areas could very well develop as part of a long range program useful to both sides. Mr. Mel'nikov would be given an opportunity to get acquainted with instrumentation and methods employed by the American side.

Mr. Balobaev is a specialist in thermal processes in permafrost. His specific interests are: geothermal processes, temperature fields in permafrost, surface heat balance as it affects the permafrost layer, heat fluxes at the bottom of the permafrost layer, contemporary balance and past development as it is affected by climatic changes, and thermal properties of frozen soils and rocks. Mr. Balobaev participates in the preparation of a geothermal map for the Soviet Union specializing in permafrost areas, which comprise a considerable part of the Soviet territory. He also utilizes available boreholes drilled for exploration purposes.

CRREL has specialists working in the field of surface heat balance. Work very similar to Balobaev's is being performed by Dr. A. Lachenbruch from the Geological Survey at Menlo Park, California. It would be useful to include Dr. Lachenbruch in discussions on the preparation of geothermal maps and CRREL will make an effort to make corresponding arrangements.

Further discussions led to an agreement that it would be very beneficial for both sides to continue cooperation in future years in permafrost problems and other topics related to cold regions. In particular either side may wish to invite specialists from other institutions as long as it is of interest to their research missions.

On a tentative basis an arrangement was discussed for 1977 whereby Dr. Mellor and Dr. Assur from CRREL would spend some time in Siberia, including Yakutsk, but especially in Akademgorodok and the Novosibirsk Library of the Academy of Sciences, supplemented by suitable field trips, largely for the purpose of preparing a substantial manuscript on excavation technology and explosive effects in frozen ground, as well as related problems.

Also as part of a possible 1977 exchange, the Soviet side would send a suitable team to CRREL. Composition and topic will be negotiated in the near future.

In 1978 another opportunity arises in connection with the Third International Permafrost Conference in Canada. A Soviet team would be invited to CRREL for a suitable length of stay.

Topics of cooperation extended for future years could include the following:

1. Effective methods for investigating morphology, structure and content of frozen layers.
2. Laws of heat and mass exchange of the upper layers of the earth's crust using methods of mathematical modeling on the basis of observations.
3. Heat exchange between cold gas lines and the environment.
4. Thermal and mechanical interactions between large dams and water reservoirs with frozen layers.
5. Site exploration by geophysical, aerial or satellite means.
6. Foundation problems, including piles in permafrost.
7. Fundamental properties of frozen soils, related to engineering needs.
8. Offshore permafrost studies.
9. Hydrological and ice engineering problems in permafrost regions.

For the purpose of obtaining more accurate information during joint studies, CRREL will explore possibilities to make available modern instrumentation to the Permafrost Institute and a specialist for installation and working instruction for Soviet specialist. Data obtained can be analyzed on American and Soviet computers.

The discussions held at CRREL proved very quickly how useful it is to bring technical administratiors from both sides together for the purpose of settling open questions. Therefore, on suitable opportunities and when a need arises, technical administrators are invited by either side to visit CRREL or the Permafrost Institute for the purpose of facilitating future exchanges of research personnel in order to solve cold regions problems by common effort.

The discussion proceeded in a friendly and constructive atmosphere with mutual respect for the interests of both parties.

This Protocol is prepared in English and Russian, both texts being equally authentic.

Hanover, New Hampshire, USA
17 June 1976

For the U.S. side:	For the Soviet side:
Dr. Dean R. Freitag Technical Director Cold Regions Research and Engineering Laboratory	Dr. P.I. Mel'nikov Director Permafrost Institute

APPENDIX B.
STUDY TOUR OF USSR
ITINERARY AND SCIENTIFIC CONTACTS

During our study tour of the USSR, we went to the following cities and locations and conferred with the following Soviet scientists and engineers, whose employing institute is given:

July 15-19, Moscow

V.T. Balobayev,	Permafrost Institute
E. Katasonov,	Permafrost Institute
N.A. Grave,	Permafrost Institute
S. Ye. Grechishev,	VSEGINGEO

July 20-21, Yakutsk

P.A. Danilovtsev,	Permafrost Institute
V.T. Balobayev,	Permafrost Institute

July 22, Chernyshevskiy

V.A. Medvedev,	Manager, Vilyuy Hydroelectric Station

July 23, Chernyshevskiy

Researchers at Permafrost Research Station:

___ Snegiryev, Director
B.A. Olovin
V. Makarov

July 24-26, on Vilyuy Reservoir

I. Konstantinov

July 27, Mirnyy

G.M. Sheynfeldt, Hydroelectric Laboratory of PROALMAZ
V. Perpisov, City of Mirnyy
__ Tikonov, PROALMAZ

July 28, Vilyuy Hydroelectric Station

V.A. Medvedev, Manager

July 29, Site of Proposed Ust'Botuobiya Dam

L.P. Belyakov, Lengidroproyekt

July 30 - August 5, Yakutsk

V.P. Mel'nikov
____ Nekrasov
V.T. Balobayev
____ Gaidayenko
____ Deryugin
P.I. Mel'nikov, Director
____ Li
____ Korotich
F.E. Are

August 6 - 9, Khorobutskaya Irrigation System and Yakutsk

R. Tzhan, Permafrost Institute

August 10, Syrdakh Lake

____ Tishin, Permafrost Institute

August 11, Yakutsk

N.V. Kal'chenko, Director GRES (a power station)
N.P. Anisimova, Permafrost Institute
____ Gavrilova, Permafrost Institute

August 12 - 15, on Lena and Aldan Rivers

V.P. Mel'nikov, Permafrost Institute
B.I. Gennadinik, Permafrost Institute

August 16 - 17, traveling to Moscow

August 18 - September 3, Moscow

Researchers from NIIOSP:

G.V. Porkhayev
S.S. Vyalov
D.I. Fyodorovich
Yu. O. Targulyan
N.P. Kazimirovna
B.A. Rzhanitsyn

Researchers from Moscow State University:

V.A. Kudryavtsev, Dean
____ Dostovalov
V.G. Melamed
____ Sovelyev

Engineers from Gidroproyekt:

G.K. Sukhanov, General Director
I.C. Moisseyev
V. Ya. Sherskov
A.L. Kuznetsov (Lengidroproyekt)
G.F. Biyanov

Researchers from MISI:

____ Shlyapin
Ya. A. Kronik
M.V. Malyshev
V.P. Merzlyakov
R.G. Pogocyan

Researchers from GISI (Gor'kiy):

P.A. Bogoslovskiy

September 4 - 12, Leningrad

Engineers from Lengidroproyekt:

L.K. Domanskiy, Chief Engineer
A.F. Vasilyev
V.A. Susloparov
Ya. E. Gluskin
V.G. Petrov
A.N. Demidov
A.L. Kuznetsov
A.N. Sizov
N.F. Krivonogova
A.P. Arsenyeva

Researchers from VNIIG:

R.V. Krasovitskiy, Deputy Director
I.N. Sokolov
Ye. A. Smirnov
Sh. N. Plyat
N.F. Shavelyev
V.A. Turchina
N.A. Mukhetdinov

APPENDIX C.
List of Publications
from the Soviet Union

Are, F.E., V.T. Balobayev and N.L. Bosikov (1974) Erosion of thermokarst lakes in central Yakutia (in Russian). In Lakes of Siberian Cryolithozone. Academy of Sciences of the USSR. Siberian Division, Institute of Cryopedology, Nov., p. 39-53. "Nauka" Publishing House.

Balobayev, V.T. and U.G. Shastkevich (1974) Calculations of pattern of talik zones and stationary temperature field of rock beneath water bodies of arbitrary form (in Russian). "Nauka" Publishing House. In Lakes of the Siberian Cryolithozone. Academy of Sciences of the USSR, Siberian Division, Institute of Cryopedology. Nov., p. 117-127.

Balobayev, V.T. (1972) Variation in thickness and temperature regime of permafrost beneath areas of sediment accumulation and denudation. Experimental studies of heat exchange processes in frozen rock, Izdatel'stvo Nauka, Moscow, p. 101-108. CRREL Draft Translation 398. AD 769722.

Balobayev, V.T. (1975) Seasonal thawing and thermo-physical properties of coarse-grained soil, (in Russian). Siberian Division. Academy of Sciences of the USSR, Novosibirsk, p. 79-86.

Biyanov, G.F. (1966) Construction and operation of low-pressure dams on permafrost soils. Trudy, IV Conference-Seminar on the Exchange of Experience in Construction Under Severe Climatic Conditions. vol. 10, CRREL Draft Translation 625. AD A041253.

Bogoslovkiy, P.A. (1950) Ice regime of hydroelectric station pipelines. Moscow-Leningrad, Gesenergoizdat, CRREL Draft Translation 605. AD A038302.

Deryugen, A.G. (1972) Strength of frozen loam (in Russian). Trudy, main administration of hydro-meteorological services, USSR, vol. 192, p. 132-138.

Konstantinov, I.P. (1976) Temperature regime of water in the near shore zone of the reservoir of Vilyuysk hydroelectric power station. Kolyma, vol. 40, p. 32-34. CRREL Draft Translation 631. AD A041434.

Korolyev, A.I. (1975) Combination of thermal with other methods of winter concreting at temperatures below minus 40°C (in Russian). Kolyma, No. 5, May p. 29-32.

Kudryavtsev, V.A., L.S. Garagulya, K.A., Kondrat'yeva and V.G. Melamed (1974) Fundamentals of frost forecasting in geological engineering investigations. Moscow University, 431 p. CRREL Draft Translation 606. AD A039677.

Kutasov, I.M. and V.N. Devyatkin (1964) Experimental investigation of the temperature regime of a shallow convective borehole. Academy of Sciences of the USSR, Siberian Division, Institute of Cryopedology. "Nauka" Publishing House, Moscow, p.143-150. CRREL Draft Translation 589. AD A037423.

Kuznetsov, G.I. (1972) Limit temperature state at permafrost earthfill dam and reservoir floor. Problems of Northern Construction, no. 2, p.50-73. CRREL Draft Translation 627. AD A041433.

Kuznetsov, A.L. (1973) Dam of the Anadyrsk thermal electric power station. Trudy Gidroproyekta, no. 34, p.88-100. CRREL Draft Translation 659. AD A047538.

Kuznetsov, G.I. and S.V. Zaslavskiy (No Date) Tailings cofferdams on permafrost foundations in Yakutskaya ASSR. Source: unknown, p. 104-115. CRREL Draft Translation 629. AD A041255.

Kuznetsov, G.I. (No Date) Evaluation of stability of earth-fill dam based on strength of frozen zones of its profile. Source: unknown, p. 182-187. CRREL Draft Translation 628. AD A041255.

Mukhetdinov, N.A. (1969) Thermal regime of the downstream shoulder of rockfill dams. Leningrad, VNIIG Izvestiya, vol. 90, p. 275-294. CRREL Draft Translation 586. AD A035988.

Mukhetdinov, N.A. (1971) Effect of non-linear air filtration on the thermal regime of rockfill dams. VNIIG Izvestiya, no. 96, p. 205-217. CRREL Draft Translation 580. AD A036092.

Mukhetdinov, N.A. (1973) Development of methods for calculation of the thermal regime of rock-fill dams in regions of severe climate. Thesis abstract, p. 2-28. Leningrad. CRREL Draft Translation 616. AD A039539.

Pekhovich, A.I., L.I. Kudoyarov and V.M. Zhidkikh (1972) Approximate calculation of the thermal regime of reservoirs formed by a frozen dam (in Russian). VNIIG Izvestiya, vol. 100. p. 146-153.

Plyat, Sh. N. (1974) Calculation of temperature fields in concrete hydraulic structures. Energiya, Moscow CRREL Draft Translation 615. AD A038303.

Pogrebiskiy, M.I. and S.N. Chernyshev (1975) Determination of the permeability of frozen fissured rock massif in the vicinity of the Kolyma Hydroelectric Power Station. Kolyma, vol. 39, no. 1, Jan. p. 28-31. CRREL Draft Translation 634. AD A041251.

Sheynfeldt, G.M. (Undated) Organization of full-scale analyses of filtration-thermal regime of tailings dams on permafrost foundations. Source unknown, p. 116-131. CRREL Draft Translation 626. AD A041432.

Ukhova, N.V. (1965) Approximate calculation of non-stationary temperature regime of a rock-ice dam. Transactions of Coordinated Meetings on Hydraulic Engineering, no. 23, p. 160-172. (MISI). V.V. Kuybyshev Moscow Construction Engineering Institute. CRREL Draft Translation 663. AD A047594.

Ukhova, N.V. (1967) Studies of non-stationary temperature regime of frozen dams made of local materials on permafrost foundations. (Author's abstract of dissertation in defense of the degree of candidate in technical sciences), Moscow. CRREL Draft Translation 665. AD A047601.